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THESIS

A NEED FOR SYSTEMS ARCHITECTURE APPROACH FOR NEXT GENERATION MINE WARFARE CAPABILITY

by

Kirk R. Hibbert

September 2006

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Today's legacy MIW processes currently employed by the warfighter, although capable of countering the mining threat, are a reactive process that is slow to engage and employ assets that are cumbersome to operate. With the advent of new technologies, a transformation of MIW capability is on the horizon and has the potential of influencing how the U.S. Navy maintains maritime dominance in the open-oceans and littoral environments.

The influence that technologies bring to MIW includes multi-spectral sensors, laser imagery, compact modular systems, unmanned and semi-autonomous weapons, as well as new communications architecture and tactics. Although these technical innovations present a level of capability superior to the existing legacy systems, developmental barriers and the lack of an overarching systems architecture will hinder or prevent these systems from being effectively integrated into tomorrow's CONOPS.

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A SYSTEMS ARCHITECTURE APPROACH FOR NEXT GENERATION MINE WARFARE CAPABILITY

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ALMDS	Airborne Laser Mine Detection System
AMCM	Airborne Mine Countermeasures
AMNS	Airborne Mine Neutralization System
ASW	Anti Submarine Warfare
C4ISR	Command Control Communication Computers Intelligence Reconnaissance
CEO	Chief Executive Officer
CONOPS	Concept of Operations
DoD	Department of Defense
EMNS	Expendable Mine Neutralization System
EOD	Explosive Ordnance Disposal
FLEX	Fatigue Life Extension
FYDP	Future Year Defense Plan
GAO	Government Accountability Office
IPPD	Integrated Product and Process Development
ISR	Intelligence Surveillance Reconnaissance
LCS	Littoral Combat Ship
LIDAR	Light Detection and Ranging
LMRS	Long Range Mine Hunting System
OASIS	Organic Airborne and Surface Influence Sweep
OMCM	Organic Mine Countermeasures
OPNAV	Chief Of Naval Operations
PEOLMW	Program Executive Office Littoral Mine Warfare
MCM	Mine Countermeasures
MDA	Milestone Decision Authority
MEDAL	Mine Warfare Environmental Decision Aid Library
MIW	Mine Warfare
MIWC	Mine Warfare Commander
MOMCOM	Mobile Mine Countermeasures Command
MOSA	Modular Open Systems Architecture
MRUUV	Mission Reconfigurable Unmanned Undersea Vehicle
MSC	Mine Countermeasures Ship Coastal
MSO	Mine Countermeasures Ship Open-ocean
P3I	Preplanned Product Improvement
PPBS	Planning Programming Budgeting System
R&D	Research and Development
RAMIC	Rapid Airborne Mine Clearance System
RDC	Rapid Deployment Capability
RMS	Remote Minehunting System
RVM	Rising Vertical Mine
SMCM	Surface Mine Countermeasures
SUW	Surface Warfare
UUV	Unmanned Underwater Vehicle
UV	Unmanned Vehicle

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EXECUTIVE SUMMARY

The U.S. Navy's objectives for projection of power and superiority of the seas are accomplished by its ability to place strategic assets anywhere in the world at anytime. Although the U.S. Navy is an effective and capable naval force, when operating in littoral environments, the threat of sea mines presents a complex challenge that can deter, or deny access to littoral environments and ultimately reduces the ability for the U.S. Navy to meet its objectives.

Mines have been successfully used as weapons at sea since the American Civil War. Today's more sophisticated sea mines employ technologies that enhance their firing logic, and stealth capability as well as their lethality. The U.S. Navy employs a mine countermeasures triad of airborne, surface and underwater assets to meet the sea mine threat. Today's countermine triad has been effective against the pre-Cold War mining threat, but as technology has changed the capabilities of mines, so too must the U.S. Navy's mine countermeasures change.

The U.S. Navy employs 1960's technology and tactics in an attempt to keep pace with new CONOPS, which are designed to counter the capabilities of today's more sophisticated sea mines in a more complex littoral environment. Although capable of countering the mine threat, dedicated mine warfare units are a reactive force that is slow to engage and cumbersome to operate in the next generation mine threat environment. Today's MIW capability requires restructuring if it is expected to keep pace with tomorrow's CONOPS. With the advent of new technology, a transformation of MIW capability is on the horizon and has the potential of influencing how the U.S. Navy maintains maritime dominance in open-oceans and littoral environments.

Technical innovations offer capabilities superior to the existing MIW systems but developmental barriers and the lack of an overarching systems architecture will hinder these systems from being effectively integrated. The focus of thesis is to identify an efficient and effective approach to infuse new technical advances and future systems into tomorrow's MIW CONOPS.

Findings of this thesis highlight a proposed architectural framework that key stakeholders can implement as a tool to guide the development of tomorrow's MIW system-of-systems. Under this proposed architectural framework as well as adherence to principles of Modular Open Systems Architecture (MOSA), achieving a capability based MIW system-of-systems is both traceable with systems engineering principles and aligned with tomorrow's war fighting vision. This thesis also finds inconsistencies with the threat sea mines bring versus the capabilities that MCM systems provide to the warfighter. Many of these inconsistencies can be attributed to a lack of commitment by the DoD in achieving a solution that meets this threat. This lack of commitment has led to crucial capability gaps in MCM such as limitations in assured access through the very shallow MCM environment and an integrated MCM capability to the Carrier and Expeditionary Strike Groups. In addition to the proposed architectural framework, a traceability matrix was developed to aligning the proposed MOSA MIW architecture with mission based scenarios and requirements. Finally, this thesis characterizes meeting tomorrow's threat through the following:

- Development of an overall MIW capabilities architect
- Adherence to established requirements
- Developing a cultural that supports an MIW architecture
- Implementing spiral development concepts to get capability to fleet sooner
- Develop a technology to counter buried mines
- Do not phase out legacy capabilities based on un-proven capabilities
- Validate system development against a traceability matrix
- Remedy important equipment shortfalls on current dedicated platforms

I. INTRODUCTION

A. BACKGROUND

Since World War II, fourteen United States Navy ships have been damaged or sunk by sea mines.[1] Since 1950 to the present, there has been no other threat that has influenced the ability to maneuver in the open-oceans and littoral environments as much as the threat of sea mines. The post-Cold War Navy has been reluctant to commit to the advent of advanced weapons, tactics or an integrated communications infrastructure to support mine warfare operations. Since the collapse of the Warsaw Pact, the U.S. Navy has shifted its focus from open-ocean and global warfare to regional and asymmetrical threats. This shift in doctrine requires a new approach to combating the mine threat.

The sea mine is an efficient force multiplier that is one of the most cost-effective weapons in the naval arsenal. Mines are small, easy to conceal, cheap to acquire, require virtually no maintenance, and can be easily laid from almost any type of platform. Sea mines can be used to deny hostile forces access to the coastal zone and to defend important targets, such as ports, anchorages, and offshore structures, from amphibious or seaborne attack. Mines can quickly nullify, or impair, the effectiveness of naval forces. For their cost, mines present a disproportionate amount of effort to counter. Because of this factor, mines are one of the most effective and deadly weapons that a naval force can employ.

Since the end of the Cold War, there has been an increase in the number of mine producing countries. Many of these producers are manufacturing mines of higher capability thus requiring a parallel increase in the technology for countering these mines. Despite the rapid trend toward more sophisticated mines, development efforts for countermine systems have been plagued with

[1] J. Avery, (1998). The Naval Mine Threat to U.S. Surface Forces, Surface Warfare, May-June, 4-9.

programmatic, developmental, cultural and integration hurdles that have the potential of derailing efforts to achieve a countermining program capable of keeping pace with and countering the threat of sea mines.

The Navy must be prepared to counter technologically advanced mines as well as their low-tech predecessors. The success of simple World War I and World War II vintage mines means that these weapons will undoubtedly continue to threaten U.S. Naval Forces.[2]

The mine threat presents a tangible challenge for tomorrow's war fighting vision. Sea Power 21 is the Navy's vision to counter the risks of traditional and emerging dangers and threats. It introduces three new operational concepts to accomplish the Navy's missions of sea control, power projection, strategic deterrence, strategic sealift, and forward presence. The first of these three pillars is Sea Strike, which projects precise and persistent offensive power. Sea Shield, the second pillar, provides global defensive assurance for the joint force and U.S. allies. Finally, Sea Basing provides operational independence and support for the joint force. These pillars of operational concepts will be enabled by an overarching communication structure identified as FORCEnet. FORCEnet is an effort to integrate warriors, sensors, networks, command and control, platforms, and weapons into a seamlessly integrated combat force.[3]

Naval Expeditionary Warfare consists of military operations mounted from the sea, usually on short notice. These operations are carried out by forward deployed or rapidly deployable, self-sustaining naval forces tailored to achieve a clearly stated objective. Expeditionary Warfare is a key tenant to the Navy's goal of power projection. To effectively achieve this objective, Expeditionary Warfare must be agile, responsive, flexible and versatile. When conducting operations

[2] Commission on Geosciences, Environment and Resources, (2000). Oceanography and Mine Warfare. (0-309-51587-4) Washington, D.C.: National Academy Press.

[3] John Young, ADM Joseph Sestak, ADM Lewis Crenshaw, LTGEN Mattis, LTGEN Robert Magnus, et al (2005, March 10). Projection Force Subcommittee on FY 2005 Navy Ship Construction Programs Washington, D.C. [Transcript]. Retrieved March 8, 2006 from http://www.house.gov/hasc/testimony/109thcongress/Projection%20Forces/NavyRDstatement3-2-05.pdf .

from the sea in littoral environments, mine warfare is an enabling mission area that facilitates an agile, flexible and versatile response. Therein lies the disconnect between the Navy's goals and its current capability. Today's mine warfare capabilities are neither agile nor responsive enough to keep pace with the proliferation of newer, more lethal sea mines. There are numerous innovative programs designed to achieve a more versatile and responsive mine countermeasures capability. Although these programs promise to bolster the Navy's mine countermeasures capability, all of these emerging programs have been hindered by developmental barriers that threaten to prevent them from being integrated into tomorrow's war fighting vision.

B. PURPOSE

The purpose of this research is to capture the risks associated with transitioning from legacy mine warfare systems and their operations, and to determine how the development of emerging technology improvements will affect the capabilities of conducting mine countermeasures operations. There are numerous business best practices and engineering disciplines that can be aligned to capture an efficient method to field newly identified technical innovations.

All Department of Defense (DoD) acquisition programs should address Modular Open Systems Approach (MOSA) early in their program and acquisition planning. Ultimately all new programs should discuss MOSA implementation in the context of their overall Acquisition Strategy and to the extent feasible in the Technology Development Strategy.[4]

Specifically, this study will focus on developing a systems architectural model that incorporates various systems architectural principles including modularity, key interfaces, requirements traceability and form and function, which

[4] Under Secretary of Defense for Acquisition, Technology and Logistics (AT&L) Memo Amplifying DoDD 5000.1 Guidance Regarding Modular Open Systems Approach Implementation, from www.acq.osd.mil/ats/opensyst.htm, 14 January 2005.

may serve as a template that will assure an effective design process to minimize capability gaps as the U.S. Navy transitions these innovative technologies to meet tomorrow's mine warfare CONOPS through the Future Year Defense Plan (FYDP) and beyond.

C. RESEARCH QUESTIONS

The research will compare and contrast today's legacy sensors, tactics and communications capability with tomorrow's mine warfare vision. This comparison will identify systematic steps necessary to align operational concepts with technical innovations bracketed under an architectural framework required to meet future requirements. This thesis will explore the following questions:

- What technology improvements have the potential to affect the architecture?
- What is the DoD current plan for fielding systems through the FYDP?
- What proposed benefit will these systems bring to the mine warfare Commander?
- How can systems architecture reduce the risks of mine warfare operations?
- How does today's CONOPS support future design of new systems?
- How does preplanned product improvement (P3I) influence CONOPS?
- How will these proposed systems influence the decision making process?
- What are the most significant technical advantages of these systems?
- What is the best approach to transition these proposed capabilities to the warfighter?
- What are the major developmental barriers?
- What can be done to maximize the benefits of new developmental systems?
- What is the best approach to integrate these systems into the Sea Power 21 framework?

D. BENEFITS OF THE STUDY

The intent of this thesis is to identify the requirements established by the Open Systems Joint Task Force and compare the initiative taken by the Expeditionary Warfare resource sponsor, Systems Commands and the warfighter to ensure the successful transition of new technologies into the existing force structure. In addition this study will compare the processes currently planned for integrating emerging technologies into the tomorrow's CONOPS.

Specifically, the study will look at emerging developmental systems: the AN/AQS-20A mine hunting sonar, AN/AES-1 Airborne Laser Mine Detection System (ALMDS), AN/SQQ-232 Airborne Mine Neutralization System (AMNS), AN/AWS-2 Rapid Airborne Mine Clearance System (RAMICS), AN/ALQ-220 Organic Airborne and Surface Sweep System (OASIS), the MH-60S Multi-Mission Helicopter, the Remote Mine Hunting System (RMS), the Mission Reconfigurable Unmanned Undersea Vehicle (MRUUV) and finally the Littoral Combat Ship (LCS). These systems have over time been subjected to programmatic and developmental changes due to the lack of a well defined overarching systems architectural structure.

Currently there are multiple individual developmental strategies for each of the respective systems with no specific strategy that ties all of these systems together as a system-of-systems. The current acquisition process approach to a successful solution for tomorrow's needs is at best ad hoc. This study will take a broad look across current DoD best practices and systems engineering disciplines and align them under one cohesive model that best meets the requirements to field these individual systems under one system-of-systems model that will be seamlessly integrated under one framework to meet tomorrow's war fighting doctrine. A comparison of best DoD and commercial business practices, trade studies, and process management will be identified and merged to provide the best solution for the acquisition community to use as a template for success.

E. SCOPE

This thesis was created to highlight the development efforts currently underway to enhance the capabilities of mine countermeasures. The reader will be exposed to the various methods that influence the acquisition as well as the design and development processes of these individual systems. The ultimate goal of this research is to capture the best methods known to both the defense and the commercial sector with respect to the design and fielding of a system-of-systems under a unified architectural framework. There are four main segments to this research:

- Chapter I introduces the research topic and provides an overview of the current structure of mine warfare as well as the direction that the Navy is heading with respect to weapon systems development and the complex tactics required to meet tomorrow's war fighting capability.
- Chapter II introduces the reader to a brief history of MIW, and then compares the acquisition process underway by the Navy's Systems Commands with requirements established by Office of the Chief of Naval Operation (OPNAV) Expeditionary Warfare's (N85) and ensures their alignment. Risk management measures will be reviewed as the Navy prepares to transition from legacy MIW systems to tomorrow's next generation system-of-systems. These new technology enhancements will be highlighted and contrasted with legacy systems as well as aligning MIW war fighting requirements. In addition the reader will be exposed to MOSA principles and how establishing a modular design affects program development and design.
- Chapter III will review MOSA, emphasizing modular design principles of systems architecture. From that, a notional architectural framework and traceability matrix will be developed to illustrate a link between tomorrow's next generation countermining capabilities to threats in varying mission environments. This notional architectural framework can serve as a template for the acquisition community to implement as a roadmap for future system-of-systems design.
- Chapter IV summarizes this research by reviewing MIW's history, the DoD's transformation plan and the best processes for providing an integrated architectural framework to meet tomorrow's MIW vision. Also, a review of emerging technologies, budgetary constrains, war fighting requirements and cultural influences, their

effects on the acquisition process and ultimately fielding of new MIW systems will be discussed.

F. METHODOLOGY

This thesis will examine documents covering best business practices for product development from the commercial industry as well as from the DoD with particular emphasis on systems architecture. Information gathered for the development of this thesis will be ascertained from data gathering from the World Wide Web, DoD and commercial product symposiums, past and present mine warfare product development strategies, interviews with key stakeholders in the DoD acquisition community and reports from program management offices.

G. MINE WARFARE CONCEPT OF OPERATION

Mine Warfare is a mission area that encompasses a wide array of assets and embodies efforts to assure access through the open-oceans and to protect our forces in the littoral battlespace. To that end an effective mine countermeasures doctrine should include an extensive infrastructure that is agile enough to maneuver with, and integrate seamlessly into tomorrow's joint war fighting vision.

Legacy MIW CONOPS focuses its effort on a pre-Cold War environment and employs five specific objectives; exploratory, reconnaissance, breakthrough, attrition and clearance operations. These objectives are accomplished by the combined efforts of air, surface and subsurface MIW assets. Exploratory operation determines whether or not mines are present. This is usually the first objective when an enemy minefield is suspected. If mines are found, the operation usually transitions to a reconnaissance objective. Reconnaissance operations are designed to make a rapid assessment of the limits of a mined area, the estimated number and types of mines present. The breakthrough objective is directed when a rapid operation is required to open channels and staging areas for an amphibious operation or break-in and or break-out of a port. This objective would be selected when there is insufficient time or forces for high percentage clearance operations. Attrition operations call for continuous or frequent mine countermeasures (MCM) efforts to keep the threat of mines to ship traffic as low as possible when traffic must continue to transit the mined waters for a comparatively long period of time. Attrition is employed when mines cannot be quickly cleared because of factors such as enemy minefield replenishment or use of mines with arming delay or high ship counter settings. Clearance is the objective of removing all the mine threat from the assigned area. Because it is difficult to ensure that all mines are cleared, a percentage goal is assigned for mine removal to permit the MCM Commander to measure and report progress.[5]

The post-Cold War era has ushered in a new era of proliferation of inexpensive mines that have the potential for deterring U.S. Naval plans from assured access to the open-oceans and the world's littoral's. The open-oceans strategies of mine clearance of yesterday have expanded to include the current strategic concept of littoral access operations. (Refer to Figure 1 The Littoral Challenge). To that end, our naval forces must have an effective mine countermeasures forces to ensure the execution of operations in today's post-Cold War era.

The U.S. Navy must be prepared to operate in distant waters in the early stages of regional hostilities to enable the flow of land-based air and ground forces into the theater of operations, as well as to protect vital follow-on sealift required for delivery of heavy equipment and sustainment of major forces.[6]

[5] Joint Pub 3-15, Joint Doctrine for Barriers, Obstacles and Mine Warfare, 24 February 1999 p. IV 12-14.

[6] John Dalton, ADM Jeremy Boorda, Gen Carl Mundy (1994), *Forward…From the Sea*, Navy/Marine Corps Strategy Statement. Washington, D.C.: U.S. Department of the Navy.

Figure 1. The Littoral Challenge[7]

For the foreseeable future, we must anticipate increases in lethality of mines, their complexity of design and the number of mines available for use by practically any adversary. Modern mine countermeasures tactics and weapon systems are pivotal if U.S. Naval Forces are to maintain a credible forward presence to ensure battlespace dominance and to conduct power projection operations.

The development of these capabilities must be guided by a well-conceived concept of operations. This concept of operations will be used to conduct and guide the development of doctrine, operations, tactics, and systems needed to defeat these dynamic naval threats. Naval mine countermeasures are unique to

[7] Navy Warfare Development Command (2003, February). *Littoral Combat Ship Concept of Operations* Version 3.1[Graphic Image], Government Printing Office, Washington, D.C.

the maritime littoral operating environment. It is a singular naval responsibility and now a core naval competency that directly affects the littoral joint force scheme of maneuver. The Mine Warfare Commander's (MIWC) primary responsibility will be to effectively fight the mine warfare battle. The MIWC will do so by adopting a layered defense concept that spans strategic, operational, and tactical war fighting levels.

H. SUMMARY

The U.S. Navy has had a long history of failing to provide for an adequate capability in naval MCM. History is full of examples from as far back as the Civil War where sea mines served as a force multiplier. Mines have decisively altered the outcomes of naval engagements in every war starting with the Russo-Japanese War. Nevertheless, the lessons learned by European navies have proven to be strikingly different from those learned by the U.S. Navy.

Most recently, Desert Storm displayed the devastating effects and mission-altering implications naval mines pose to the naval commander. Desert Storm provided the U.S. with the shocking effect that a couple of cheap and primitive mines could have on the entire Fleet from a psychological standpoint as well as a strategic-operational standpoint. The raid on Faylaka Island, and subsequent amphibious assault to Kuwait, were eventually cancelled by U.S. Navy’s Central Command because the risk of mines was considered too high. On February 19, 1991 a $1500 contact mine of the World War I vintage blew a 16-by-25 foot hole in the *USS Tripoli’s* hull, and an Italian-made influence mine almost sank the *USS Princeton.* [8]

Since the Persian Gulf War, the U.S. Congress has paid particular attention to the efforts placed on mine warfare and has concluded after an extensive Government Accountability Office (GAO) study in 1998 that the U.S. Navy had not established clear priorities among its MIW research and development programs to sustain the development and procurement of the most

[8] Don Ward (1993 June 28), Mine Boggling, *Navy Times*, No. 38, 28, p. 14.

needed systems. Consequently, the Navy experienced delays in delivering new systems to provide necessary capabilities. Establishment of a long-range plan must be developed to identify gaps and limitations in the Navy's MCM capabilities and establish priorities. The DoD states the process was ongoing and consisted of developing an overall concept of MCM operations and an architecture within which needs and shortfalls in capabilities could be evaluated and prioritized.[9]

Without question mine warfare is a multi-faceted war fighting discipline that requires a great deal of effort to counter a fairly simple, but extremely effective weapon. History has revealed that the sea mine’s lethality, ease of acquisition and simplicity to employ, makes it the weapon of choice for super powers, allied as well as rogue nations. It isn’t a matter of if, but when terrorist groups will employ the use of sea mine as a weapon to force their fundamentalist demands on unsuspecting nations.

As the world’s greatest naval force, the U.S. Navy will have to take stock of its existing MIW capabilities, refocus its research and development efforts and shape the aforementioned technologies into a formidable capability that assures the U.S. an ability to counter any sea mine threat anytime and anywhere. There are a number of programs on the horizon that when aligned will yield a MIW capability second to none. This study will highlight those programs; along with best business practices both adopted by the DoD and the commercial sector. It will take commitment by all key stakeholders to ensure its success as the Navy proceeds to achieve its goals for the 21st century.

[9] GAO Report to the Chairman and Ranking Minority Member, Subcommittee on Military Research and Development, Committee on National Security, House of Representatives June 1998 NAVY MINE WARFARE Plans to Improve Countermeasures Capabilities Unclear.

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II. ILLUSTRATING THE DYNAMICS

A. INTRODUCTION

"The idea of design─of making something that has not existed before─is central to engineering."[10] A projected architectural end state for any program, structure, community, system, or system-of-systems can evolve over time, or can be explicitly designed and adhered to from the project's inception. Mine countermeasures includes elements of both evolutionary design as well as designs that are explicit. Although much of MIW architectural design has been influenced by evolution, explicit MIW architectural design was first seen with such developments as the Admirable class minesweeper and Airborne Mine Countermeasures (AMCM). The Admirable class ships built during the 1940's were the first attempt to refine the requirements by the U.S. Navy to combat the threat of sea mines, while the use of helicopters during the Vietnam conflict to conduct mine sweeping from an altitude that provided safety and the tactical advantage of speed. These two innovations were implemented as explicit systems to improve the capabilities of mine countermeasures. Over the following fifty years, the architectural design of MIW continued to be influenced by explicit as well as evolutionary design.

B. HISTORY OF MINE WARFARE

The Battle of Mobile Bay during the Civil War stemmed the initial need to counter the threat of sea mines which was forever etched in U.S. Naval history by Admiral Farragut's quote, "*Damn the torpedoes*" referencing the destructive effect by the first generation of sea mines. Followed some forty-years later during the Russo-Japanese War of 1905, where uncontrolled Russian mining of Tsushima Straits resulted in the sinking of massive quantities of neutral shipping. This uncontrolled mining ultimately led to the first Hague convention where

[10] Henry Petroski (1992). *To Engineer is Human: The Role of Failure in Successful Design,* Preface, Vintage Books, New York.

worldwide attention was paid to mining. Inspired by the principle of the freedom of sea routes and the common highway of all nations, an international accord was subsequently enacted as a result of observing the conflict of World War I. The Hague Conference was convened in 1907 as the first attempt to negotiate viable restrictions upon the employment of mine warfare by belligerent nations. Essentially, four basic points were agreed upon: it was forbidden to lay drifting mines unless "they are so constructed as to become harmless one hour at most after those who have laid them have lost control over them," it was forbidden to lay "automatic contact mines which do not become harmless as soon as they have broken loose from their moorings," it was forbidden to lay automatic contact mines off the coasts and ports of the enemy with the sole purpose of intercepting commercial navigation; and every possible precaution must be used to ensure safe navigation to non-belligerent's when moored minefields are employed. These agreements were largely unenforceable and (from a military standpoint) essentially impractical if mining was to offer any tactical or strategic advantage as borne out by the actions of the belligerents during World War I when they were largely ignored. The Hague agreements were scheduled for renewal in 1914, but the war prevented it, consequently the stipulations of the original 1907 Hague Convention were never updated or amended. It remains, for all practical purposes, the basic international agreement on mine warfare in force today.[11]

The naval mine emerged as the allies' primary and most effective weapon against the German submarine during World War I. American and British minelayers planted over 72,000 mines in the North Sea over a five month period from Scotland to Norway. This mine barrage sank six submarines, damaged many more, and forced U-boat commanders to either face destruction or waste precious time and fuel evading the barrage.[12]

[11] Sam Tangredi (2004*). Globalization and Maritime Power: Low Tech Warfare in a High tech World*, Institute for National Security Strategic Studies, National Defense University: University Press of the Pacific.

[12] E. B. Potter (1981). *Sea Power: A Naval History*, U.S. Naval Institute Press.

In the years of peace that followed World War I, the sea mine was all but forgotten. However, with the start of World War II, mine development was revived. The airplane and submarine were introduced as minelayers and a new series of mines were designed. These mines employed electronic detectors which responded to, or were actuated by magnetic, acoustic, or pressure changes resulting from a ship entering the mine's sensor range. The extensive use of mines armed with new electronic detection systems, ship-counters and arming-delay devices placed an immense burden on the mine countermeasures forces.

The advent of new mine technology ushered in the introduction of specified mine countermeasures systems and mine threat self protection measures. A direct and explicit means to counter the sea mine threat led to the development of the Admirable class fleet mine sweeper, where two prototype vessels were produced in 1942. As conflict escalated, a number of companies increased their production efforts to supply the U.S. Navy as well as some allied forces with this newly designed minesweeper. Incredibly nine companies would launch 120 Admirable class minesweepers between October 1942 and the end of World War II. With the war over and post war minesweeping completed, most of the Admirable minesweepers were decommissioned and placed in the U.S. Navy's reserve fleets. A few would remain in commission and would serve as training vessels for a number of years to come.[13]

At the beginning of the Korean War, seven Admirable class minesweepers were brought back into service to aid the Fleet against the sea mine threat as the U.S. redefined its MCM capability with the creation of two specific classes of MIW ships to counter the mining threat in different environments. The ocean going minesweeper (MSO) and the coastal minesweeper (MSC) class ships were

[13] Robert Briggen (1999).*How The Admirable's Fit Into World War II and After.* Retrieved May 8, 2005 from https: http://members.aol.com/turkit/page14.html.

developed to counter sea mines in the open-oceans as well as coastal zones. Many of the weapon systems developed during this period are still in use today.[14]

The Vietnam conflict ushered yet another MCM capability. The introduction of AMCM added another dimension to the battle against the sea mining threat as helicopters were introduced as an airborne MCM capability. AMCM assets are unique in their capability to deploy rapidly, provide rapid reconnaissance and precursor MCM operations as well as being safer and more capable than surface mine countermeasures (SMCM) assets against the shallow water mine threat. On January 27th, 1973 Task Force 78 was formed to conduct minesweeping operations in North Vietnamese waters under the name Operation Endsweep. By February 6th, 1973 surface minesweepers of Task Force 78 began preliminary sweeping to prepare an anchorage in deep water off the approaches to Haiphong Harbor. This was a first in mine warfare as airborne minesweeping had never been done with live mines.[15]

From the Vietnamese harbors to the Suez Canal and Persian Gulf, the role of MIW continued to be further defined. As this warfare discipline evolved over time the introduction of Explosive Ordnance Disposal (EOD) units added identification, neutralization and provided the Navy's only very shallow water zone mine countermeasure capability to mine warfare.

The effect of mining had a significant impact on the Persian Gulf region for several decades. During October 1973, the end of the Arab-Israeli war exploited the capabilities of EOD teams. For a six-year period, the Suez Canal between Egypt and the Israeli occupied territory in the Suez region had been closed during the conflict. Under the agreement that ended the war, an international force would clear the canal of 8,500 pieces of wreckage, unexploded ordnance, and mines. The Commander of the U.S. Sixth Fleet in the Mediterranean

[14] Bill Marks (1998). Mine Warfare MCM Introduction: The Threat. Retrieved May 10, 2005 from http://www.fas.org/man/dod-101/navy/docs/swos/cmd/miw/Sp6-4-1/sld001.htm.

[15] Naval Historical Center, Operation Pocket Money and Operation Endsweep, Retrieved May 10, 2005 from http://www.globalsecurity.org/military/ops/pocket_money.htm, May 11, 2006.

established Task Force 65, the MCM Force responsible to Sixth Fleet to handle the U.S. contribution to the clearance efforts of the Suez Canal. Admiral Brian McCauley, who was the Commander of the MIW Forces, led the U.S. Forces that swept North Vietnam's harbors at the end of the Vietnam War and was assigned command of U.S. and international MCM forces. Despite the fact that there was little intelligence on mines that might be in Suez waters, planning for the operation moved ahead swiftly. The U.S. Navy deployed an AMCM squadron, HM-12 along with the Mobile Mine Countermeasures Command (MOMCOM) to conduct MCM operations. This force operated from the amphibious assault ships USS *IWO JIMA* and USS *INCHON*. Working expeditiously, the helicopters swept 120 square miles of canal.[16]

Figure 2. SMCM and AMCM MCM Operations, Persian Gulf, 1987[17]

[16] Tamara Melia (1991) *Damn the Torpedoes, A short history of U.S. Mine Countermeasures, 1777-1991* Washington: D.C. Naval Historical Center.

[17] Michael Palmer (1992). *Guardians of the Gulf.* [Photograph], Free Press, New York.

Following operations in the Suez, the 1980s and 1990s revealed further emphasis for the need to focus on the enabling aspects of maritime mine warfare, which time and again throughout history has been proven to be a show stopper, but has received an inadequate amount of financial support, especially during the Cold War years. In the 1980s there was the experience of Operation *ERNEST WILL*, commonly known as the "Tanker War" and in the early 1990s there were *DESERT SHIELD* and *DESERT STORM* which saw effective hunting and sweeping against more than 1300 sea mines laid in the Persian Gulf, which included both WWII era as well as modern more sophisticated influence mines. It was during *DESERT STORM* that both the USS *Princeton* and USS *Tripoli* were damaged by Manta and LUGM-145 mines respectively. The combined damage to both ships totaled $21.6 million, where the estimated cost for one mine was $10,000 and $1,500 for the other, illustrating the disproportionate cost of damage to threat relationship.[18]

The structure of the U.S. Navy's Mine Force has evolved throughout history in an attempt to keep stride with the development of sea mines. The threat posed by these weapons continues and is increasing in today's world of inexpensive advanced electronics and multiple potential enemies. During the Cold War, U.S. Naval Forces concentrated on guarding against the sophisticated Soviet blue-water, air, and undersea threats. Yet since World War II, U.S. Naval Forces have suffered significantly more physical damage and operational interference from sea mines than from air, missile, and submarine attacks. The need for U.S. Naval Forces to maneuver and project power in the world's littorals is also increasing. Yet the U.S. is not now likely to be able to adequately handle the near-term threat of mines. Looking ahead, the Navy's planned mine warfare

[18] Commander Mine Warfare Command (2002). Mine Warfare History: Concept of Operations Retrieved May 15, 2006 from https://www.cmwc.navy.mil/COMOMAG/Mine%20 History/Vision%20Statement.aspx.

improvement programs have major shortcomings that need to be addressed now if current risks are to be reduced rather than permitted to continue to grow.[19]

C. OPERATIONAL ANALYSIS

Existing MCM operations are conducted to clear enemy minefields to a specified objective, which takes into account an established risk level to shape the battlespace and to project power from the sea. Legacy airborne, surface and EOD MCM forces are used to conduct dedicated mine countermeasure operations. The strength of today's dedicated forces lies with their ability to conduct sustained MCM operations in large areas over extended periods of time. Their key limitation is the length of time it takes to reposition the surface contingent of the triad from continental U.S. homeports to a theater of operation in time of conflict. A small number of ships are forward deployed to mitigate this deficiency; however, the requirement remains for the Navy to have a more robust capability available globally on short notice.[20]

1. Legacy Concept of Operations

When naval forces must operate in mined waters, dedicated mine countermeasure operations are used to reduce the threat of mines to an acceptable level to permit operations through sea lines of communication and within amphibious and naval operating areas. Legacy MCM tactics are determined by the time and assets available. The time required to move MCM units to the minefield area as opposed to the time available for completion of MCM operations is a key determination. A primary mission of AMCM forces is to provide short-notice, rapid response to any mining threat. AMCM currently operates under a 72-hour ready-to-deploy requirement. AMCM assets can self

[19] Commission on Physical Science, Mathematics, and Applications (2001). *Naval Mine Warfare: Operational and Tactical Challenge for Naval Forces* (0-309-07578-5), Washington, D.C. National Academy Press.

[20] Mine Warfare Sub-committee, Expeditionary Warfare Committee, National Defense Industry Association, (2000) *NDIA N-85 MSC Study Final Report*, Washington, D.C.; Government Printing Office.

lift, provided they are in close proximity to the area of operation. If not they must be airlifted by C-5 *Galaxy* aircraft, or transported by a surface vessel. When conducting operations, AMCM forces sacrifice some degree of effectiveness and stamina to maximize response capability. SMCM forces are more effective but, because of their relatively slow transit speeds, have a long response times. For long distances, heavy lift ships can transport SMCM units to the area of operations more quickly than the MCM ships could transit on their own. Whenever time and circumstances permit, AMCM assets should be used for precursory minefield sweeping before operating SMCM assets. This provides a greater safety margins for surface craft, which lack the helicopter's relative immunity to mines. EOD diver systems and marine mammal systems conduct identification, neutralization and very shallow water MCM operations after the mine threat is localized by either AMCM or SMCM forces. EOD teams constitute the only means for hunting and clearing mines from shallow inshore waters.[21]

2. Alignment of Systems Requirement

The capabilities of MCM have improved over the decades to meet the threat of sea mines, but although capable of countering this threat, by its very nature MCM has evolved as a result of new mine developments and changing threat environment. Notwithstanding the capabilities of today's MIW forces, the logic behind the evolution of MCM has been flawed.[22] This logic has provided the U.S. Navy with a warfare discipline that is slow to engage, cumbersome to operate and is not integrated within the strike group.

Conducting MIW operations in the Cold War environment enabled an effective solution to the mining threat of that era. As the DoD embraces post-Cold War doctrine highlighted in literature such as "*Forward…From The Sea"* and its predecessor "…*From the Sea,"* fighting the unknown enemy in an

[21] Joint Staff, (1999) *Joint Doctrine for Barriers, Obstacles and Mine Warfare* Joint Pub 3-15, Countering Enemy Employment.

[22] Tamara Melia (1991) *Damn the Torpedoes, A short history of U.S. Mine Countermeasures, 1777-1991* Washington: D.C. Naval Historical Center.

asymmetric environment places tremendous burden on the CONOPS of legacy MIW. This new shift in warfare doctrine has caused a shift in the DoD's focus to align its capabilities with a new agile way of fighting the enemy.

The Secretary of Defense, Donald Rumsfeld, has lectured in various forums as well as communicated with the American public, Congress and our senior military leaders in the direction of change, or transformation for the DoD. Transformation is a process that shapes the changing nature of military competition and cooperation through new combinations of concepts, capabilities, people and organizations that exploit our nation's advantages and protects against our asymmetric vulnerabilities to sustain our strategic position, which helps underpin peace and stability in the world.

> Preparing for the future will require us to think differently and develop the kinds of forces and capabilities that can adapt quickly to new challenges and to unexpected circumstances. An ability to adapt will be critical in a world where surprise and uncertainty are the defining characteristics of our new security environment. During the Cold War, we faced a fairly predictable set of threats. We came to know a great deal about our adversary, because it was the same one for a long period. We knew many of the capabilities they possessed, and we fashioned strategies and capabilities that we believed we needed to deter them. And they were successful. It worked.[23]

Enemy mines and obstacles pose perhaps the most significant challenge to the U.S. Navy and Marine Corps ability to project full dimension naval power from the stern gate, over water, across the beach, and to objectives ashore. Legacy naval MIW forces, although highly capable, require significant time to move to theater, and require unique support not found elsewhere in the naval expeditionary force. At the same time, the adequacy of legacy MIW capabilities is deteriorating with the proliferation of new technologies and weapons. The transformation of naval mine warfare is centered upon the transition from a specialized MIW force to an agile, scalable capability that is not tied to dedicated

[23] Donald Rumsfeld (2002, January 31). [Address]. Address presented at the National Defense University. Fort McNair, Washington, D.C. [Transcript]. Retrieved May 23, 2006 from http://www.defenselink.mil/speeches/2002/s20020131-secdef.html.

platforms, with the ultimate goal of removing the man from the minefield by the use of unmanned vehicles. Naval efforts in offensive, defensive, and assault-breaching MIW will address the challenges of restricted capabilities and proliferating threats by moving to a range of solutions which are more flexible, more effective and more rapidly employable. A significant body of analysis has verified that simple avoidance will not be an option in many key areas of national interest. In these areas the current “Detect and avoid when possible, breach when necessary” approach must be taken. The transformational naval approach to MIW is based on a CONOPS that integrates a range of new technologies that will enable future naval forces to freely operate and maneuver in the littorals, and deliver ground forces throughout the beach regions.[24]

To meet future MIW requirements, the Navy has developed and funded a plan to provide the MCM Commander with capabilities organic to Carrier and Expeditionary Strike groups. These new capabilities were initially planned for a 2005 fleet deliver, but have shifted due to programmatic delays. The suite of next generation MCM systems have subsequently been rescheduled for fielding in 2007. This next generation MCM capability ranges from airborne sensors and neutralizers designed for use aboard the MH-60S helicopter, to a sensor capable of being employed by the MH-60S as well as the Remote Minehunting System (RMS). In addition to these sensors and search platforms, the Navy is investing in the capability of a Mission Reconfigurable Unmanned Undersea Vehicle (MRUUV), an autonomous system which will be designed to be launched and recovered from U.S. Navy submarines to search, locate and classify mine-like objects in suspected mine danger areas as well as other clandestine operations. Linking these elements together under an umbrella of data fusion and transfer is the Mine Warfare Environmental Decision Aid Library (MEDAL).

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[24] Gordon England, ADM Vern Clark, GEN Michael Hagee (2003) *Assured Access and Projection of Power…From the Sea:* Naval Transformation Road Map 2003. Washington, D.C.: Department of the Navy.

3. Risk Management

While the Navy plans the acquisition strategies for transitioning the MIW forces to meet the requirements of tomorrow's war fighting vision, a concerted effort must be made to ensure that support for legacy MIW capabilities remain intact. In an attempt to mitigate gaps in the Navy's MCM capability the Expeditionary Warfare Committee, commissioned by OPNAV N85, examined the risks associated with transitioning the MIW forces to meet tomorrows MIW CONOPS. The conclusion of the study highlighted the need to maintain an effective MCM capability while the Navy transitions to an organic MCM force structure. In the end, a mix of legacy and organic surface and airborne forces is envisioned to satisfy the required roles and missions over the wide spectrum of threats and scenarios in an uncertain future. It is the opinion of the National Defense Industry Association study group that prematurely implementing the transition plan based on yet to be demonstrated capabilities would have a high degree of risk.[25]

In the conduct of today's MCM operations, Commander Mine Warfare Command (CMWC) employs two classes of MIW ships to conduct surface mine countermeasures; the MHC *Avenger* Class and the MCM *Osprey* Class MIW ships and utilizes the MH-53E Sea Dragon helicopter for AMCM operation. Both SMCM and AMCM platforms are reaching the end of their service life while the proposed fielding plans for the newly designed MIW systems are planned for fleet introduction. As with many newly developed systems, programmatic hurdles tend to affect fielding time lines, consequently both AMCM and SMCM acquisition programs have seen their share of delays. The risks associated with this reduction in MCM forces may negatively impact tomorrows MIW capability. Currently the Navy plans to divest the Fleet's inventory of all the MHC's by FY-08

[25] Mine Warfare Subcommittee, Expeditionary Warfare Committee, National Defense Industry Association. (2000). *NDIA MCS Study*. Final Report Washington, D.C. Government Printing Office.

coincident with the introduction the Littoral Combat Ship, a new modular designed ship capable of conducting Anti-submarine Warfare (ASW), Surface Warfare (SUW) and MIW operations.[26]

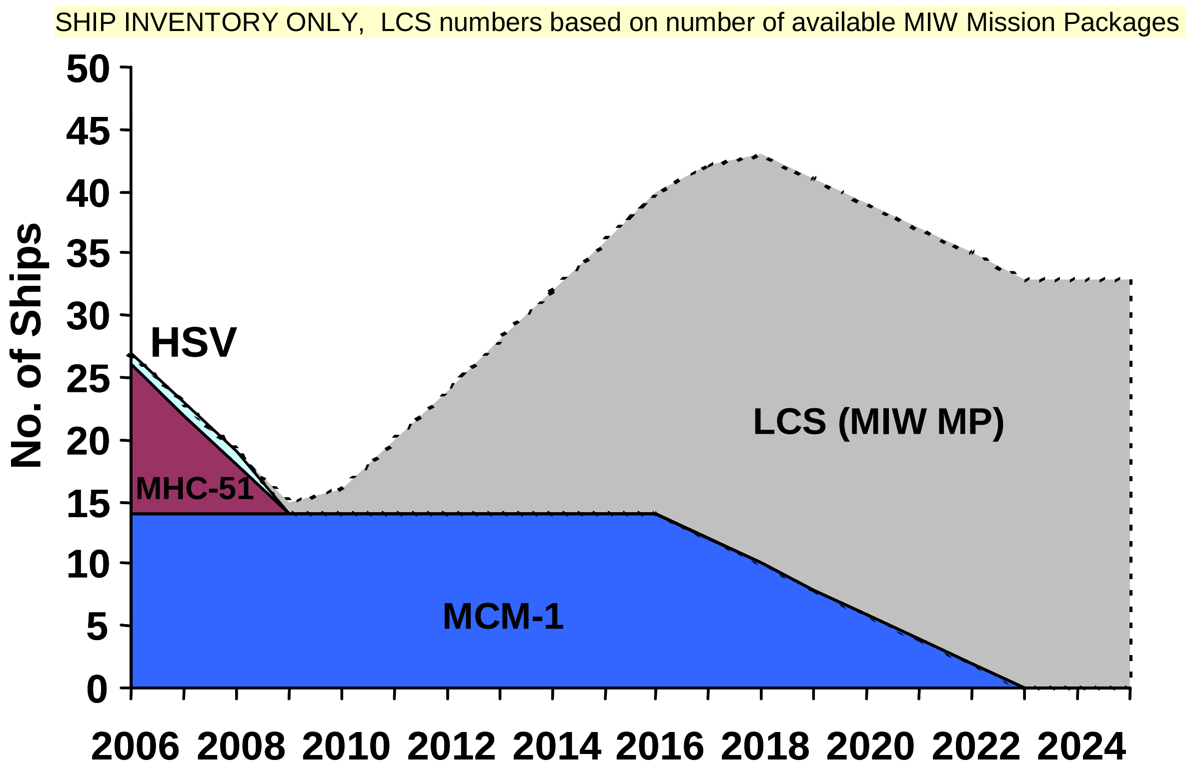


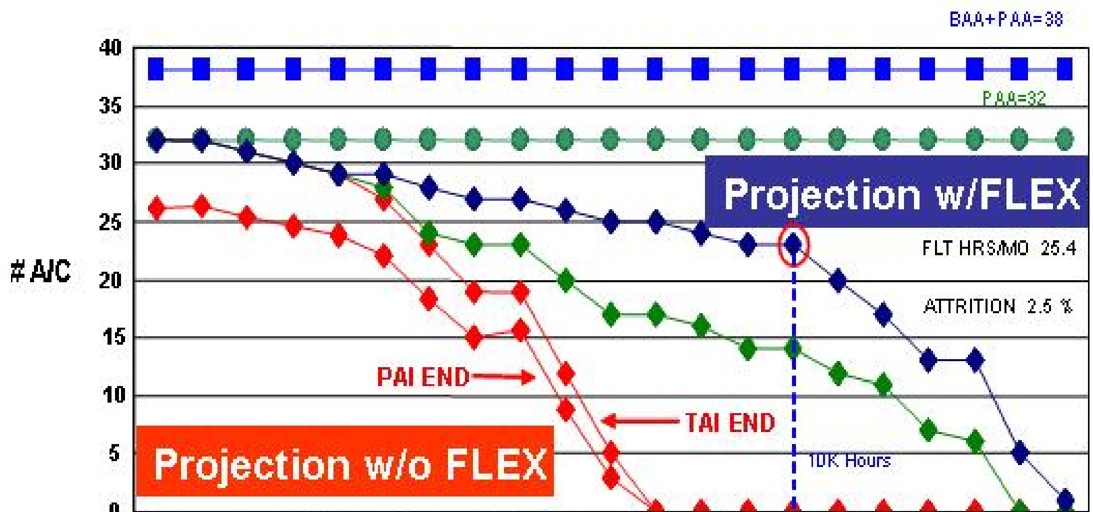
Figure 3. SMCM Platform Inventory Projections[27]

The MH-53E *Sea Dragon* multi-mission helicopter, an MCM asset employed by CMWC as one of the three pillars to MCM, is primarily employed as an AMCM platform with the secondary mission of heavy lift logistics. Produced in the early 1980's, there are currently 31 helicopters in the Navy's inventory. The airframe is designed to operate in austere environments or from expeditionary

[26] Edward Miller (2006, May 10). Mine Warfare: Dedicated, Organic a way forward for MCM Operations. Lecture provided to AMCM leadership during MH-53E community developed by OPNAV N-85 and PEO LMW, PMS 495. Corpus Christi, TX.

[27] Jason Lopez (2006). Surface Mine Countermeasures [Chart]. From PMS 495 Mine Warfare Presentation (p. 7). Washington, D.C.: PEO LMW Washington Navy Yard.

surface vessels and other combatants at sea. The MH-53E is a proven AMCM platform capable of towing a variety of MCM systems. The aircraft's was original designed with a service life that limited each airframe to 6900 hour of operating time. The total average life on the fleet of helicopters is approximately 4100 hours, with the first of the aircraft expected to reach the end of its service life in FY-07. [28]



FY	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
BAA+PAA	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
PAA	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
TAI END	32	32	31	30	29	27	23	19	19	12	5	0	0	0	0	0	0	0	0	0	0
PAI END	26	26	25	25	24	22	18	15	16	9	3	0	0	0	0	0	0	0	0	0	0
TAI 20	32	32	31	30	29	28	24	23	23	20	17	17	16	14	14	12	11	7	6	0	0
TAI 32	32	32	31	30	29	29	28	27	27	26	25	25	24	23	23	20	17	13	13	5	1

Figure 4. MH-53E Attrition With and Without the Fatigue Life Extension[29]

Mitigation plans for both AMCM and SMCM are underway to minimize potential gaps with tomorrow's next generation MIW capability as a consequence of decommissioning the MHC ships and the attrition of the MH-53E helicopter. Programmatic changes for SMCM include funding of the mid-life upgrade plan

[28] Jack Fulton (2006, March 22). H-53 Heavy Lift Helicopter Lecture provided to the All Helicopter Operational Advisory Group developed by PMA 261, Patuxent River, MD.

[29] Jack Fulton (2006). Heavy Lift Helicopter [Chart]. From PMA 261. All Helicopter Operational Advisory Group Presentation (p 8) Patuxent River, MD. PMA 261 Naval Air Station PAX River.

that greatly enhances the performance of the MCM-1 Class ships. Reduction of the MHC-51 Class ships enables investment in the critical technologies required for achievement of the MCM vision with a minimal reduction in capability and no reduction in response time considering operational requirements and timelines. Including an improved mine neutralizer; the Expendable Mine Neutralization System (EMNS). Additional upgrades will provide an improved capability which include the following:

- Replacement of the Mine Neutralization System (AN/SLQ-48) with the EMNS
- Modernization of acoustic sweep systems with the Advanced Acoustic Generator (AAG) and the Infrasonic Advanced Acoustic Generator (IAAG), replacement of current AN/SQQ-32 Sonar with a High Frequency Wide Band capability and communications suite modernization (HF only)
- Isotta-Fraschini Engine Planned Product Improvement Program for 5 remaining ships
- Aft Deck Equipment upgrades will remove deteriorating and heavy hydraulic systems, replacing them with reliable electric motors reducing maintenance requirements and five tons of weight
- Bow thruster Improvement program will replace the thrust vane monitor optic sensor, hydraulic actuators and accumulator with supportable units and adds a reduction gear hand pre-lube pump
- Digital Voltage Regulator program will replace the existing outdated ships service electric Voltage regulator with a Digital Voltage Regulator
- The 400 Hz Static Frequency Converter upgrade[30]

Programmatic changes to AMCM force structure include a budget funded, $4.0M Fatigue Life Extension Program (FLEX) commencing in fiscal year 2007. The FLEX includes a structural enhancement prior to airframes reaching the 6900 hours operating limitation to reinforce a critical flight station. This improvement will extend the service life of the aircraft to 10,000 hours of use. The FLEX will cover 20 AMCM capable airframes to ensure operational plan

[30] Edward Miller, (*personal communication,* May 10, 2006). Topic of discussion was managing risks when divesting the Fleet of Coastal Mine Hunting Ships.

requirements can be met until next generation systems are fielded and mature. The FLEX will provide a sustained capability during transition to future MCM systems.[31] In addition to extending the service life of the MH-53E, the Program Executive Office, Littoral Mine Warfare (PEO LMW) is also establishing the MH-53E as a test and evaluation platform for verification and validation of the AN/AQS-20A mine hunting sonar, the *Archerfish* AMNS and the AN/ALQ-220 OASIS. This mitigation plan accomplishes two objectives. The first is being to validate and verify testing requirements for each of these newly designed weapon systems while concurrent testing is being conducted on the Block II variant of the MH-60S. Without this concurrent testing of both the MH-60S and the weapon systems, testing would have to be accomplished serially with the MH-60S taking precedence. Conducting this testing serially would ultimately delay program maturity by extending the timeline for testing both the MH-60S and the weapon systems. Secondly, while conducting testing of the weapon systems on the MH-53E, a proven integration plan would provide flexibility to enable these next generation systems to be deployed on both the MH-53E as well as the MH-60S.[32]

4. Transition Requirements for MIW CONOPS

Future MCM operations will utilize a network of next generation sensors and weapons that can be optimized for each threat, depth, and environmental regime. Effective organic MCM operations will depend on a complementary "system-of-systems" approach to achieve success. This requires pursuit of a rigorous investment strategy, leveraging commonality, modularity, and portability to develop and integrate a range of new technologies and systems. Organic MCM capabilities, along with a balanced supporting force of dedicated MCM assets will enable our deployed forces to maneuver while executing other combat

[31] Jack Fulton (2006, March 22). H-53 Heavy Lift Helicopter Lecture provided to the All Helicopter Operational Advisory Group developed by PMA 261, Patuxent River, MD.

[32] Jason Lopez (*personal communication,* March 3, 2006). Topic of discussion: managing risks when conducting alternate platform testing.

missions. Transitioning the next generation MIW systems to tomorrow's war fighting vision will have to follow the guidance of an architectural framework that will align these system-of-systems to tomorrow's CONOPS. In order to eliminate the delay of getting the dedicated forces to the fight, an Organic Mine Countermeasures (OMCM) CONOPS has been developed. OMCM capabilities will decrease the response time required to commence the MCM campaign and expand the service's overall MCM capability. It will integrate the next generation MCM sensors and weapons as part of the combat systems of ships, submarines, and helicopters embedded in the Carrier Strike and Expeditionary Strike Groups.[33]

The Littoral Combat Ship (LCS) will be the organic platform that will be designed from the keel up to be a part of a netted and distributed force. The key war fighting capability of LCS will be its off-board systems: manned helicopters and unmanned aerial, surface and underwater vehicles. Its modular design, built to MOSA architecture standards, provides flexibility and a means to rapidly reconfigure mission modules and payloads. Approximately 40% of LCS's payload volume will be reconfigurable. As technology matures, the U.S. Navy will not have to buy a new LCS seaframe, but will upgrade the mission modules or the unmanned systems. LCS will be different from any warship that has been built for the U.S. Navy. The program provides the best balance of risk with affordability and speed of construction.[34]

D. THE ACQUISITION PROCESS

Integral to MOSA, the acquisition process is intended to be flexible and to accommodate systems and technologies of varying maturities. Systems

[33] ADM Jay Johnson, GEN James Jones (2000). *U.S. Naval Mine Warfare Plan, Fourth Edition Program for the New Millennium* Department of the Navy, Washington, D.C.

[34] John Young, VADM Joseph Sestak, ADM Lewis Crenshaw, LTGEN Mattis, LTGEN Robert Magnus, et al (2005, March 10). Projection Force Subcommittee on FY 2005 Navy Ship Construction Programs Washington, D.C. [Transcript]. Retrieved March 8, 2006 from http://www.house.gov/hasc/testimony/109thcongress/Projection%20Forces/NavyRDstatement3-2-05.pdf.

dependent on immature technologies will take longer to develop and produce, while those that employ mature technologies can proceed through the process relatively quickly. Acquisition programs shall be managed through the application of a systems engineering approach that optimizes total system performance and minimizes total ownership costs. A modular, open systems approach shall be employed, where feasible. The Under Secretary of Defense for Acquisition, Technology and Logistics signed a memo that amplified and expanded the policy for implementation of MOSA. This directive establishes that all programs subject to milestone review shall brief their program's MOSA implementation status to the Milestone Decision Authority (MDA) to determine compliance. The Director of Defense Systems signed a memo that describes how the requirements stipulated in the memo should address systems-of-systems requirements in the formal acquisition process. Based on the instructions contained in the memo, all DoD acquisition programs should address MOSA early in their program and acquisition planning, and should discuss MOSA implementation in the context of their overall Acquisition Strategy and to the extent feasible in the Technology Development Strategy.[35]

How does MOSA align with tomorrow's next generation MIW CONOPS? To characterize the ideals of this directive, the Modular Open Systems Approach is both a business and technical strategy for developing a new system or modernizing an existing one. It is a means to assess and implement, when feasible, widely supported commercial interface standards in developing systems using a modular design concepts. MOSA is an enabler that supports program teams in the acquisition community to design for affordable change, employ evolutionary acquisition, spiral development and develop an integrated roadmap for weapon systems design and development. Basing design strategies on widely supported open standards increases the chance that future changes will be able to be integrated in a cost effective manner. Designing a system for

[35] Office of the Under Secretary of the Navy. (2004) *Instruction for Modular Open Systems Approach (MOSA) Implementation.* Washington, D.C.: Government Printing Office,

affordable change requires modularity. An evolutionary acquisition strategy provides a foundation that meets existing needs while providing the capability to meet evolving requirements and threats. An integrated roadmap is a tool for detailing the strategy to deliver weapon systems that is capable, upgradeable, affordable, and supportable throughout its planned life-cycle.[36]

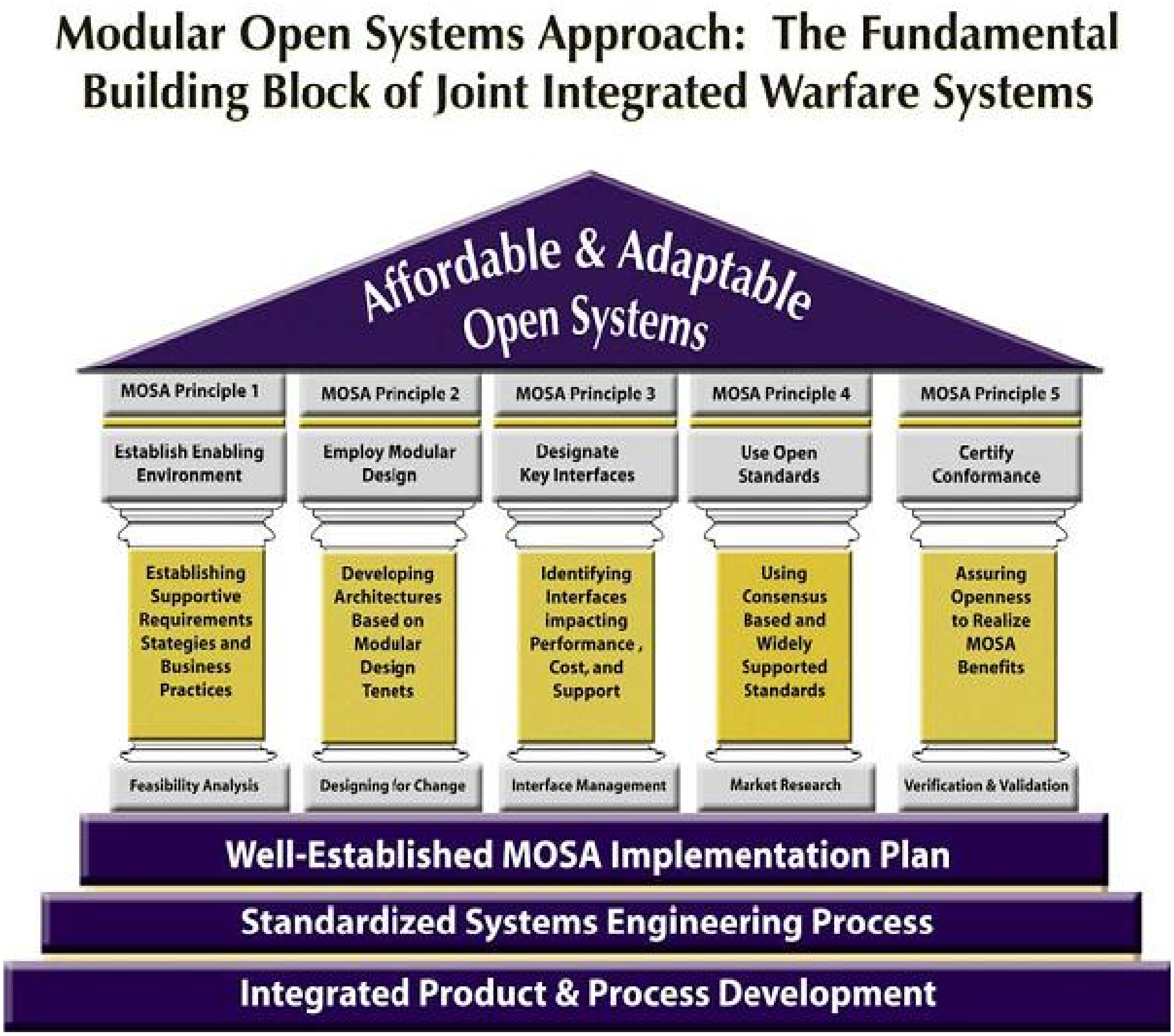


Figure 5. The MOSA Framework[37]

[36] Open Systems Joint Task Force. (2004). Program Manager's Guide, *A Modular Open Systems Approach (MOSA) to Acquisition,* (Version 2.0). Washington, D.C. Government Printing Office.

[37] Open Systems Joint Task Force. (2004). Program Manager's Guide [Graphic Image], *A Modular Open Systems Approach (MOSA) to Acquisition,* (Version 2.0). (p. 10). Washington, D.C. Government Printing Office.

The principles of MOSA align itself with the visions of a transformational DoD and provides the basic tenets necessary to achieve future capability while managing the risk of an evolving threat as well as changes in technology. Although MOSA provides a framework for managing systems development, it lacks a linkage to ensure the transition of today's capabilities with tomorrow's plan. There are, however, tools within the MOSA framework that can be implemented to characterize risks associated with transitioning today's MIW capabilities with tomorrow's newly designed MIW system-of-systems. To align the next generation organic MIW developmental systems with tomorrow's war fighting concepts while simultaneously managing capability gaps, we must clearly understand tomorrow's organic requirements and align them with today's dedicated capabilities as well as capture these elements under the MOSA architectural construct.

1. Aligning Future CONOPS and Capabilities

Requirements are at the heart of all developmental programs. Tomorrow's next generation system-of-systems is no exception. Organic MCM systems are being developed to permit naval forces to operate and transit in a mined environment without having to await the arrival of dedicated MCM forces. Focusing primarily on the area that stretches from deep water to the 40-foot depth curve, organic assets will provide a highly capable, albeit reduced, capacity across the MCM requirements spectrum. Specifically, the Carrier Strike Group Commander will have a full range of organic MCM capabilities embarked as an integral part of the strike group. These shipborne assets will give forward deployed forces the ability to conduct timely MCM operations, allowing for unencumbered transit and minimizing the operational delay or impact of mines.[38]

[38] GEN William Whitlow (2002 April 9). [Address] Address presented before the Sea Power Subcommittee of the Senate Arms Services Committee on the Navy Marine Corps Operational Requirements for the 21st Century. Washington, D.C. [Transcript]. Retrieved May 28, 2006 from http://www.chinfo.navy.mil/navpalib/testimony/seapower/wawhitlow020309.txt.

At the outset it must be noted that there is no "silver bullet" in MCM. The different types of threat mines and environmental conditions that will face our naval forces argue for a system-of-systems which is robust and flexible enough to operate in regimes from waters in excess of 200 feet in depth to the surf zone and craft landing zone on the beach. Technology will not support single platforms or sensors to perform the MCM mission across the spectrum of threats.[39]

The primary objective of near-term improvements of Navy MCM is to reduce the operational response and MCM tactical timelines. The response timeline for current MCM forces is constrained by the speed of strategic lift or surface transit time from the continental United States (CONUS) or overseas stations to the area of conflict. From CONUS, MCM command elements, AMCM forces, and MCM EOD forces can be airlifted to theater and become operational within 10 days. However, SMCM forces must sail directly to theater or travel on specialized heavy-lift ships, requiring 30 to 60 days. The Navy is forward-basing MCM assets in some potential conflict areas, specifically the Western Pacific and Arabian Gulf, significantly reducing the time required for SMCM forces to respond to joint commanders in charge of MCM requirements in two likely areas of confrontation. However, overall response times remain too long for many likely contingencies.

Organic MCM sensors are being developed to answer many of the unique challenges associated with MCM. The threat of sea mines comes in many different forms. Moored mines are by far the most common in the world's war stocks and any minefield encountered will probably contain mostly contact mines of varying types. Contact mines are detonated when the ship strikes them. Bottom mines lie on the ocean floor at varying depths and can be detonated by an acoustic, magnetic, pressure or a combination of these influences. Some moored mines can also be actuated by external influences. To further

[39] Naval Research Advisory Committee. (2000). Unmanned Vehicles (UV) In Mine Countermeasures, Washington, D.C., Government Printing Office.

complicate the MCM challenge, mines can have selective time delay fuses. This lets the mine become active after a certain day and, if no targets have passed over it after a certain period; the mine enters a dormant stage, making it inoperative and will reactivate when a ship enters its sensor range again. They also have similar multiple target ship count devices which allows a predetermined number of ships to pass before detonation. Rising vertical mines (RVM) and anti-countermeasures dormancy capabilities in today's most complex sea mines increase the complexity of countering the mine threat. An RVM is a mine designed for use in either very deep water, which could not otherwise be mined, or where the seabed is soft and glutinous. The rising mine lies on or under the sea floor. It is normally equipped with a passive acoustic sensor to listen for a ship or submarine to pass within range. When contact is made, it switches to an active mode and jettisons ballast to change its buoyancy from negative to positive. This causes it to float up and explode at the appropriate moment. Counter countermeasures features enable a mine to render itself dormant when it senses it is being interrogated. Finally, there are new materials used as mine casings such as plastics and fiberglass in addition to casings designed to camouflage these weapons to mimic rocks.[40]

A significant shift of functional roles between dedicated and organic MCM will be the phasing out of the MH-53E helicopters and the concurrent fielding and full operational capability of organic AMCM resident in multi-mission capable MH-60 airframes. The transition of airframes will be without degradation of the forces' surge capability that the current AMCM construct provides. This capability will be inherent in CONUS-based MH-60 squadrons that are not deployed but otherwise engaged in various phases of inter-deployment training and maintenance.[41]

The goal of organic mine countermeasure operations is to enable naval forces to conduct their war fighting missions without being exposed to the risks of

[40] Stuart Slade (2000). *Mine Warfare.* The Naval Technical Board. Retrieved June 16, 2006 from http://www.navweaps.com/index_tech/tech-068.htm.

[41] ADM Jay Johnson, James Jones (2000). *U.S. Naval Mine Warfare Plan, Fourth Edition Program for the New Millennium* Department of the Navy, Washington, D.C.

operations in mined waters. Naval forces can begin to shape the battlespace by conducting organic mine countermeasure operations by utilizing mapping, survey and intelligence databases which have been updated and detailed through mine countermeasure surveillance operations. This approach to MCM will provide combatants the ability to detect and avoid sea mines. Information provided by organic mine countermeasure operations will also be used to plan and focus the efforts of arriving dedicated mine countermeasure forces should they be required to conduct mine clearance operations to further shape the battlespace.[42]

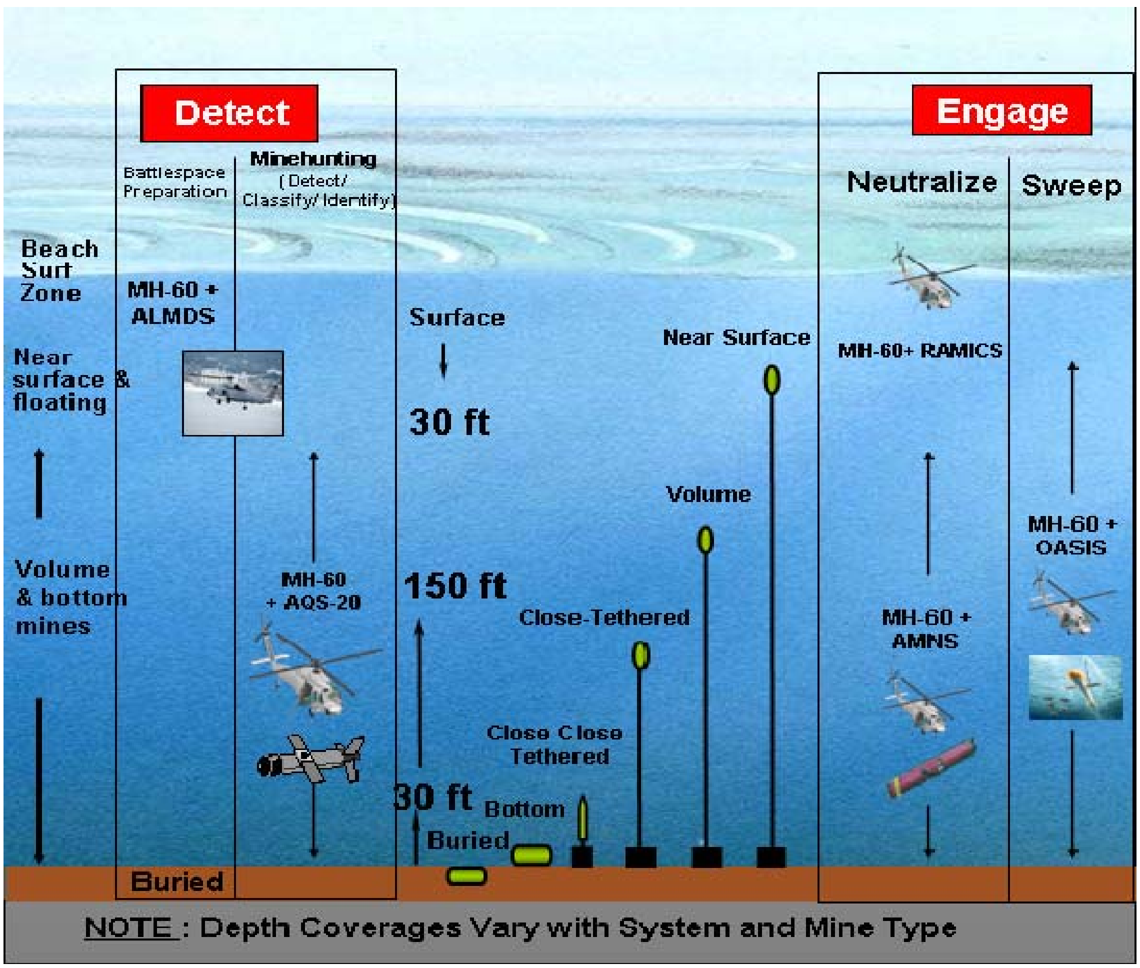


Figure 6. AMCM Organic Mine Countermeasures Engagement Envelope[43]

[42] Chief of Naval Operations (OPNAV N852), (1995). Concept of Operations in the 21st Century. Washington, D.C. Government Printing Office.

[43] Jason Lopez (2006). Surface Mine Countermeasures [Graphic Image]. From PMS 495 Mine Warfare Presentation (p. 13). Washington, D.C.: PEO LMW Washington Navy Yard.

a. AN/AQS-20A Mine Hunting System

The organic MCM systems-of-systems are designed to provide this rapid capability for the Carrier and Expeditionary Strike Groups. As mentioned above, there is no one “silver bullet” that will counter the mine threat. Tomorrow’s suite of organic systems are designed to counter sea mines in varying environments ranging from deep water to the shallow water zones of the world’s littoral regions. To prosecute mines throughout varying depths, a suite of organic MCM system-of-systems will be utilized to survey, localize, identify and neutralize these threats. These systems include the AN/AQS-20A, which is a system designed to be towed by a helicopter or the RMS. The towed body includes side-looking (SLS), gap-filling (GFS), volume-searching (VSS), and forward-looking sonar’s (FLS).

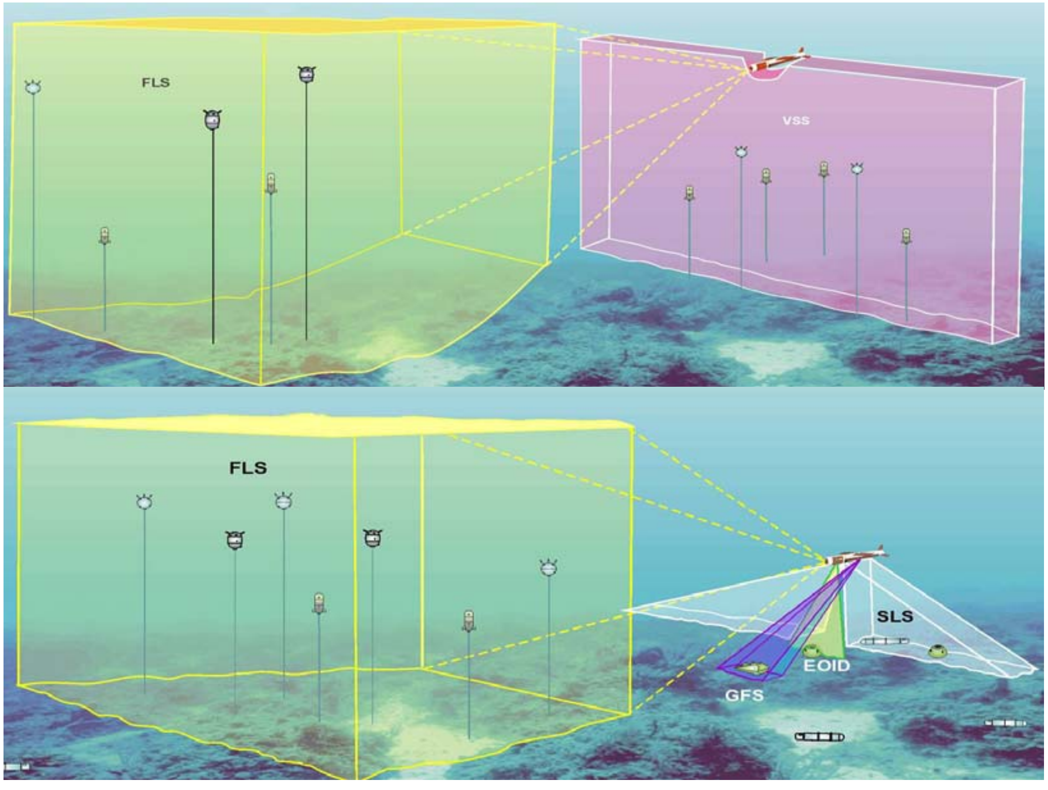


Figure 7. AN/AQS-20A Sonar and Electro-optic Identification[44]

[44] Jason Lopez (2006). Surface Mine Countermeasures [Graphic Image]. From PMS 495 Mine Warfare Presentation (p.13). Washington, D.C.: PEO LMW Washington Navy Yard.

The AN/AQS-20A will be effective against bottom and moored mines in both deep and shallow waters. It will provide an increase in area coverage rate in comparison to the current AN/AQS-24A sonar system currently employed by dedicated AMCM helicopters. In addition to its sonar's, the AN/AQS-20A sonar system can be fitted with an integrated electro-optic identification (EOID) device which will provide an identification capability of previously localized mine like objects. Unlike the AN/AQS-24A's laser identification device, the EOID of the AN/AQS-20A must be installed after the volume search sonar has been removed. It is designed to provide a rapid detection, classification, localization, and identification of bottom, close tethered, and volume mines. This capability will enable combatants at sea to transit or avoid mined areas in choke points and littoral areas with a high degree of self-protection.

DT-IIF Minefields: Performance Comparison	AN/AQS-14A	AN/AQS-20A	Improvement
VOL: P_{cmm} PMA	A	1.67A	67%
VOL: ASR	B	23.81B	2281%
SPD: P_{cmm} PMA	C	2.50C	150%
SPD: ASR	D	7.44D	644%
SPS: P_{cmm} PMA	E	1.05E	5%
SPS: ASR	F	3.32F	232%

Table 1. Sonar Performance Capability Comparison[45]

b. Localization of Surface and Near Surface Mines

For several years, the U.S. Navy has been evaluating electro optics as a method of locating sea mines. Lasers have become more powerful and compact and their wavelengths more tunable. The use of a blue-green laser, which has a frequency compatible with seawater, allows a Light Detection and

[45] Jason Lopez (2006). Surface Mine Countermeasures [Chart]. From PMS 495 Mine Warfare Presentation (p. 13). Washington, D.C.: PEO LMW Washington Navy Yard.

Ranging (LIDAR) system to provide accurate information on the characteristics of targets at various water depths. This technology will provide the Fleet self protection when traveling through choke points and confined straits, as well as rapid reconnaissance of minefields in support of amphibious operations. The AN/AES-1 ALMDS is an electro optics mine reconnaissance system that detects and localizes drifting, floating and shallow water moored mines from the MH-60S helicopter. This non-towed system is designed for use in the surface and near surface engagement envelope. ALMDS represents a capability that does not exist in today's mine countermeasure inventory. As a non-towed system, ALMDS provides flexibility to the helicopter crews to transit a suspected area of interest without the restrictions of towed systems. This is a new rapid search and reconnaissance capability of floating and near surface mine for the MCM force.

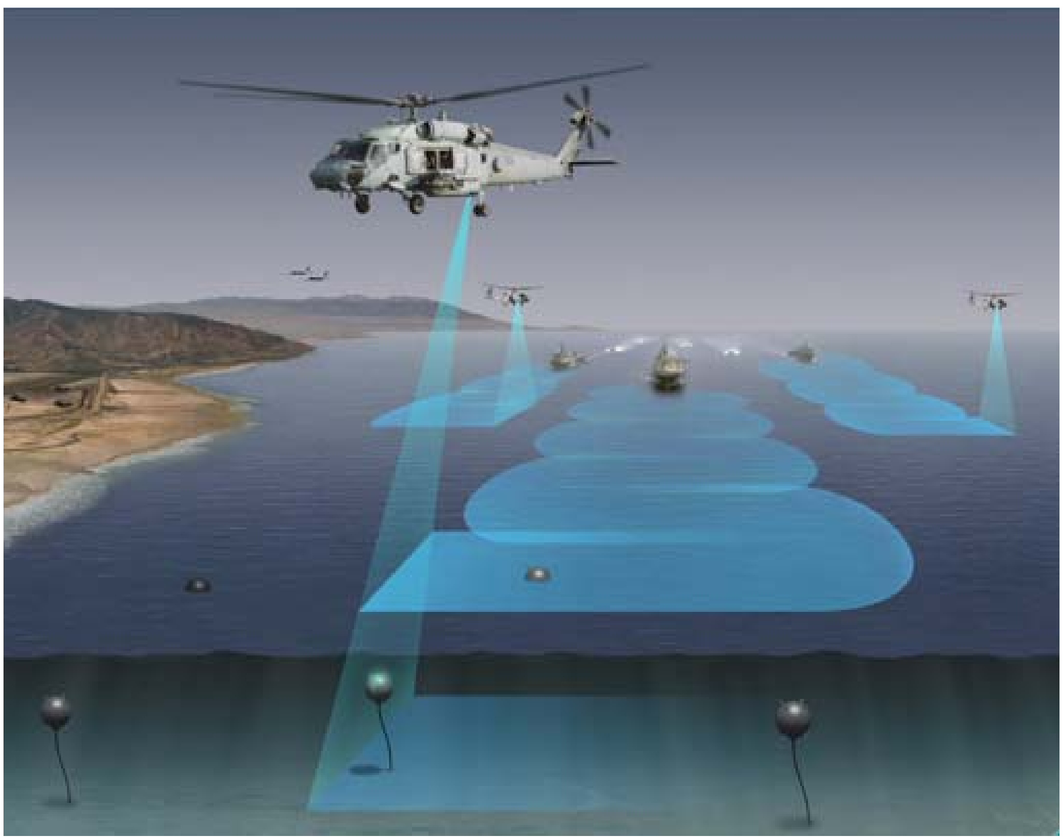


Figure 8. Airborne Laser Mine Detection System[46]

[46] Areté Associates (2005). Airborne Laser Mine Detection System [Graphic Image]. Retrieved June 16, 2006 from www.arete.com/index.php?view=still_mcm.

c. Neutralization Capabilities

The Airborne Mine Neutralization System (AMNS) will be fielded in two versions designed to be deployed by both the organic and dedicated airborne assets. Both systems will provide a capability to target sea mines by a remotely operated, expendable, mine neutralization system. The system is designed to work in concert with sonar systems. The sonar systems localize and identify sea mines, after which the AMNS reacquires and destroys the mines with a self contained shaped charge. MH-60S aircrews will utilize the Archerfish neutralization system to remotely navigate to the target from the helicopter using information gained from the systems onboard sonar and ultimately its camera while in close proximity to its intended target. After the neutralizer reaches its target, the operator initiates the burning of the shaped charge, which destroys the target. The MH-53E utilizes the Seafox, which is currently deployed under a Rapid Deployment Capability (RDC). The AMNS System was originally designed for use aboard the MH-53E. Although the Seafox was near completion, programmatic changes with the development of the AMNS system led to the creation of a new more compact system that would be fielded aboard the MH-60S. The AMNS Seafox RDC provides a limited identification and neutralization capability to the dedicated AMCM force. Both the Archerfish and Seafox are designed to counter mines in the near surface to sea bed engagement zone.

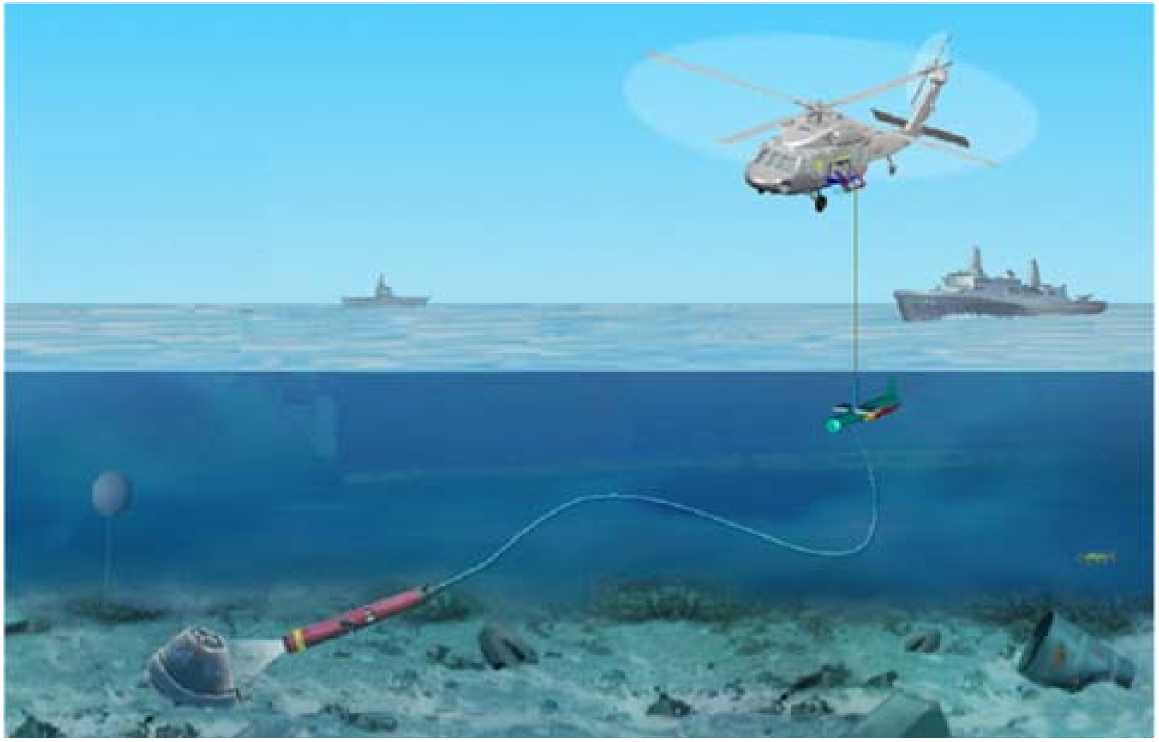


Figure 9. Archerfish Airborne Mine Neutralization System[47]

The Rapid Airborne Mine Clearance System (RAMICS) is another neutralization capability planned for the next generation MCM systems. It is designed as a helicopter-borne weapon system that fires a special 20mm supercavitating projectile from a modified Bushmaster high velocity gun. The system has a blue-green LIDAR which searches for floating or near surface mines and targeting laser system that locks on to the mine with the gun's targeting laser that works in conjunction with the gun's computer to neutralize surface and near-surface mines.

[47] Jason Lopez (2006). Surface Mine Countermeasures [Graphic Image]. From PMS 495 Mine Warfare Presentation (p. 13). Washington, D.C.: PEO LMW Washington Navy Yard.

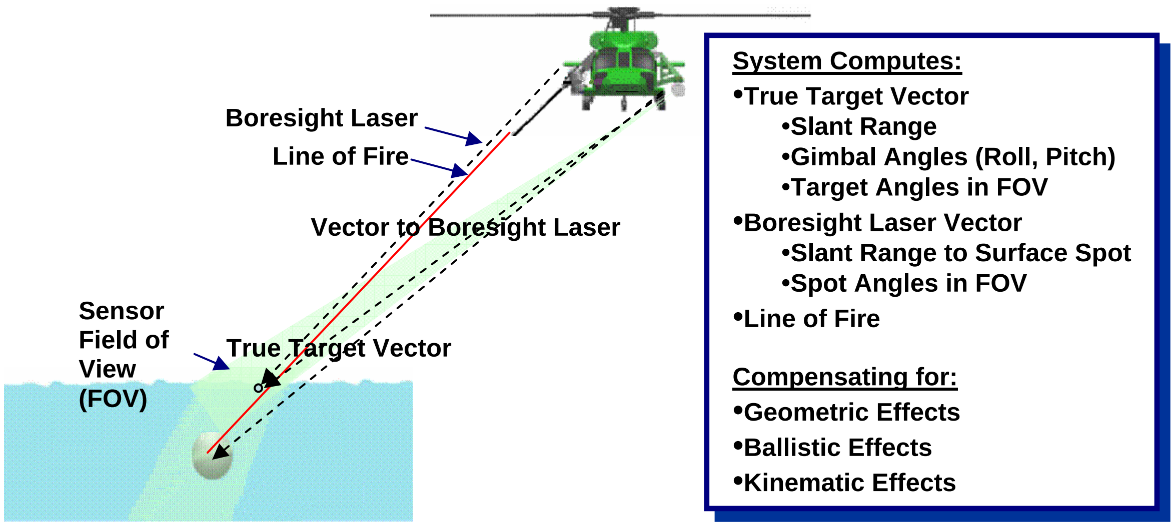


Figure 10. Rapid Airborne Mine Clearance System[48]

d. Airborne Influence Mine Sweeping

When it is impractical to hunt or neutralize sea mines due to environmental conditions, sweeping for mines is a tactical initiative used to minimize the risk of encountering influence sea mines. The Organic Airborne and Surface Influence Sweep (OASIS) is a high speed magnetic and acoustic influence mine sweeping system designed to support mine clearance operations. It consists of a towed magnetic and acoustic source, a tow and power delivery cable, a power conditioning and control subsystem, and an external or palletized power supply. Its ability to fully demagnetize allows the system to be transported in the helicopter allowing for fast transit to over the horizon operating areas. This system is designed to counter influence mines from the near surface to sea bed engagement zones.

[48] Jason Lopez, J. (2006). Surface Mine Countermeasures [Graphic Image]. From PMS 495 Mine Warfare Presentation (p. 21). Washington, D.C.: PEO LMW Washington Navy Yard.

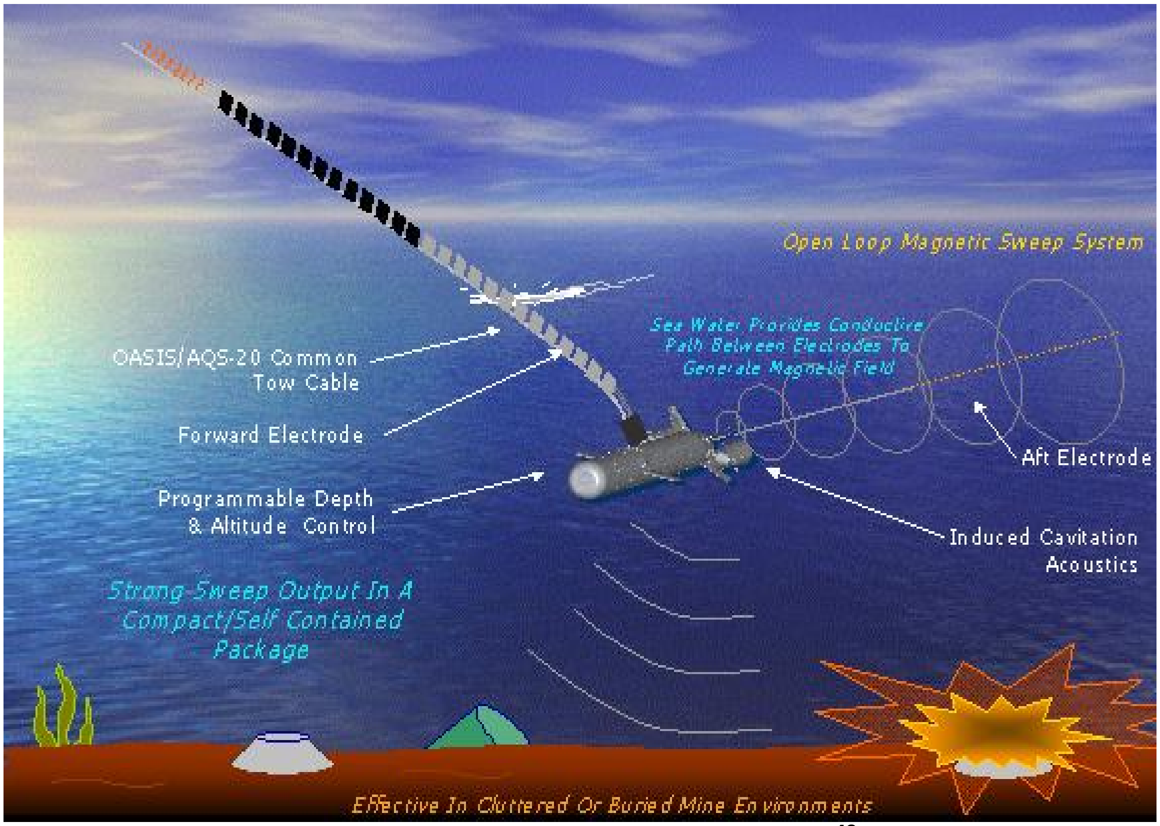


Figure 11. OASIS Concept of Operation[49]

Dedicated MCM employs a similar system; the MK-106 which delivers a greater power output from its magnetic generator. This increase in power output subsequently produces an increased magnetic influence signature greater than that of the OASIS influence system. Although the legacy system produces an increased signature, it comes at a cost; the legacy system can not be carried internally to the helicopter which limits its ability to conduct operations over the horizon at distances away from the helicopter's host platform.

e. Reconnaissance and Surveillance Operations

Working in conjunction with the organic airborne assets the AN/WLD-1(V)1 Remote Minehunting System (RMS) is a system that operates remotely away from its host platform. The RMS is designed to meet fleet

[49] Jason Lopez, J. (2006). Surface Mine Countermeasures [Graphic Image]. From PMS 495 Mine Warfare Presentation (p. 27). Washington, D.C.: PEO LMW Washington Navy Yard.

requirements for beyond line-of-sight mine reconnaissance against bottom and moored mines in deep and shallow water regions. This semi-autonomous system will detect, classify, identify and localize volume, and tethered, close-tethered, mines and record their precise location for avoidance and, or subsequent removal. The system has been designed to be integral to forces deployed anywhere in the world, providing an organic mine countermeasures capability to surface combatant forces in the absence of dedicated mine countermeasure forces. RMS will provide continuous, unmanned, over-the-horizon capability to determine the presence or absence of mines.

The RMS will be installed first on DDG 91 and then on the following *ARLEIGH BURKE* Class hulls. It will be fully integrated into the ship's undersea warfare combat system and include a launch and recovery system integral to the ship. Other surface ships that are being considered as host platforms are the High Speed Vessel-X2, which will be an interim replacement for an MCM command ship and the Littoral Combat Ship (LCS).[50]

[50] Naval Surface Warfare Center, Panama City FL Remote Mine Hunting System Focus Sheet, Retrieved June 18, 2006 from: //www.ncsc.navy.mil/Our_Mission/Major_Projects.

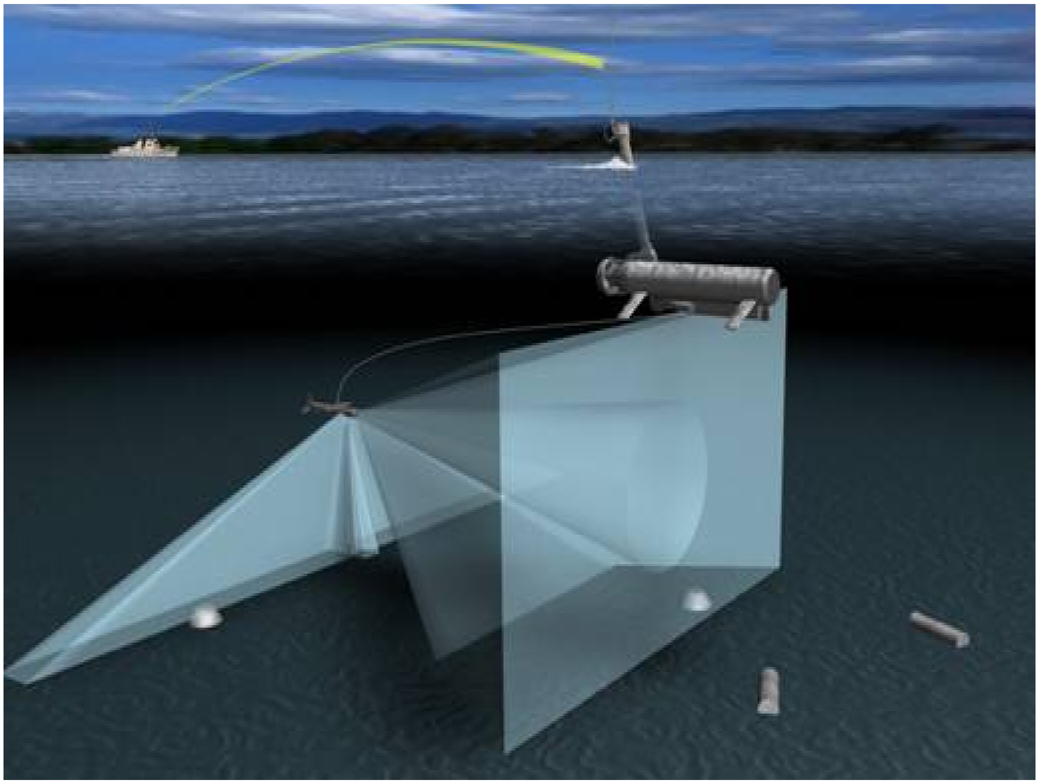


Figure 12. Remote Mine Hunting System with AN/AQS-20A Sonar[51]

A key requirement of Sea Power 21 is the ability to use the sea as maneuver space while operating in the complex littoral threat environment and potential contested or denied waters. This environment poses a very robust surveillance threat of coordinated attack from land, air, and sea-based weapons systems, including sea mines. A basic tenet of sea based maneuver warfare is the ability to apply our resources against the adversary's weaknesses. To this end, forward deployed naval forces must possess an organic intelligence, surveillance, and reconnaissance capability with which to clandestinely assess the presence and extent of the threat and to identify the location of suspected threats. Such an organic capability must be responsive to strategic, tactical and on scene commander tasking and would typically be used in advance of other forces entering a denied area.

[51] SpaceDaily (2004, August 31). Unmanned Remote Mine Hunting System Installed for USS Momsen Commissioning. Retrieved June 28, 2006 from http://www.spacedaily.com/news/uav-04zzo.html.

In support of strategic requirements or prior to operations in potentially contested or denied waters the Mission Reconfigurable Unmanned Undersea Vehicle (MRUUV) will be deployed from submarines to conduct Intelligence, Surveillance, and Reconnaissance (ISR), Anti-Submarine Warfare (ASW), MCM and additional data collection operations. Although no single system can provide the required capability in all tactical situations against the full scope of threats within the entire battlespace, the MRUUV system will have the clandestine reconnaissance and communications capability to assess potential operating areas in preparation for future operations. Planning data about an area and a potential adversary may include, but is not limited to: electronic order of battle, detection of critical radio frequency signatures, force disposition, level and content of communications, movement of troops and material, details of shore installations and meteorological information required in support of potential military operations.

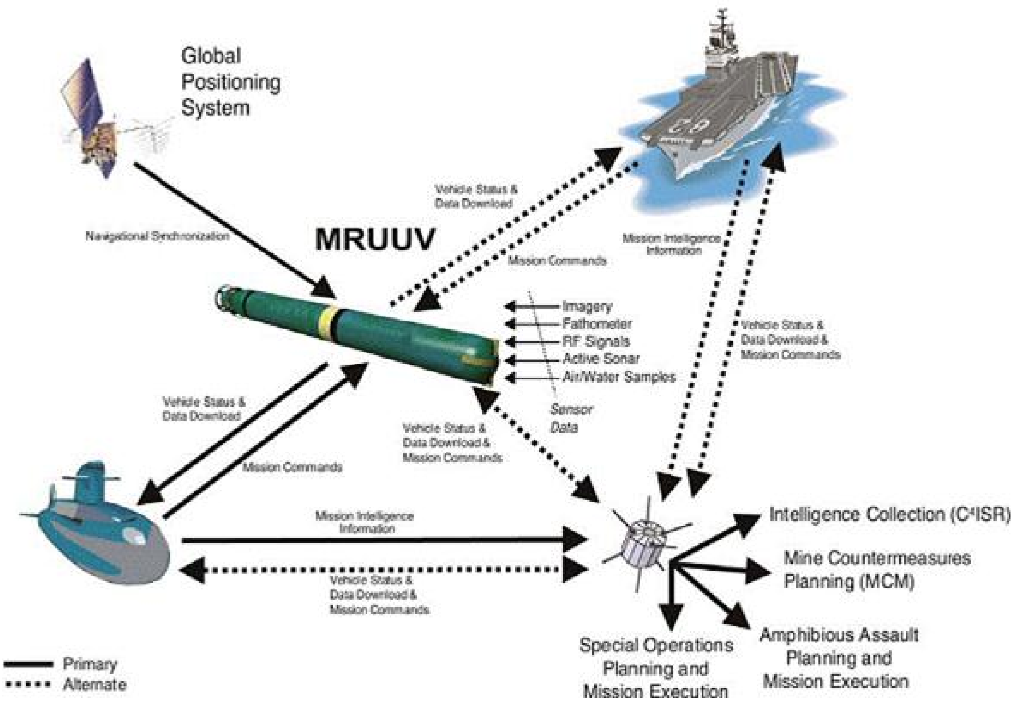


Figure 13. MRUUV Operational Concept Graphic[52]

[52] (2003, January). 21" Mission Reconfigurable Unmanned Undersea Vehicle (MRUUV) System Concept of Operation.

To connect tomorrow's MIW system-of-systems together under an effective war fighting discipline, data from surveillance, reconnaissance, environmental conditions, mine identification, battle damage assessment, as well as topographical data will require a netted system that warfare commanders will utilize to construct war fighting plans. As an enabler of Sea Power 21, FORCEnet provides the link of all war fighting data connected under the discipline of C4ISR. As an integral naval component of the DoD wide Internet Protocol based advanced network, FORCEnet will provide the open architecture and building blocks that integrate sensors, networks, decision aids, weapons, warriors, and supporting systems into a highly adaptive, human-centric, comprehensive system that operates from seabed to space and from sea to land. By facilitating comprehensive battlespace awareness, it will support the attainment of dimensional superiority by geographically dispersed forces as they execute a wide variety of missions across the entire range of military operations. It is focused on accelerating the speed and accuracy of information gathering, assessment, decision and action at every level of command.[53]

Mine warfare command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems will link the Mine Countermeasures Commander with mine warfare forces and other Expeditionary Warfare elements. Linking the overarching littoral MCM war fighting picture has taken on a new thrust with the development of an embedded capability within the C4ISR network. To better understand and quantify the significance of the mine warfare problem, the U.S. Navy has embarked on a course that includes coordination and analysis of worldwide seafloor data and development of mission planning systems, such as the Mine Warfare Environmental Decision Aid Library (MEDAL). MEDAL uses descriptive parameters to define bottom composition for a wide range of depositional environments. Information can be obtained in situ from diver reports, extracted from acoustical data, or viewed from a video camera

[53] Gordon England, ADM Vern Clark, GEN Michael Hagee (2003) *Assured Access and Projection of Power…From the Sea:* Naval Transformation Road Map 2003. Washington, D.C.

on a mine neutralization vehicle. Bottom sediment databases containing 70 categories of sediment descriptions are automatically input into MEDAL. Bottom roughness and clutter density databases are input into MEDAL as defined by MIW doctrine. Incorporation of the MEDAL tactical decision aid into Joint Maritime Command Information System and the Global Command and Control System Maritime has strengthened the Mine Countermeasures Commander's relationship to the Carrier Strike and Expeditionary Strike Groups digital information exchange, and contribution to the common operational picture.[54]

2. Summary of Dedicated MCM Limitations and Benefits

In reviewing future concepts and operational drivers basic to the conduct of effective mine warfare activities; the most pertinent operational benefits and limitations of legacy MIW system-of-systems include:

- High infrastructure and support costs for dedicated MCM
- Dedicated surface MCM require lengthy transit times
- No beyond-line-of-sight data transfer capability for dedicated systems
- Dedicated AMCM is limited to daytime only operation
- Significant personnel and equipment are needed to conduct and sustain MH-53E operations
- Potentially long transit distances are associated with land basing
- Reduced overall area coverage rates for dedicated sonar systems
- The MH-53E has a higher sustained mission time than the MH-60S
- Dedicated AMCM and EOD systems are deployed reasonably rapidly
- Dedicated AMCM and EOD can achieve high area coverage rates
- Sustained MCM clearance operations can be achieved with dedicated systems

[54] Commission on Geosciences, Environment and Resources, (2000). Oceanography and Mine Warfare. (0-309-51587-4) Washington, D.C.: National Academy Press.

3. Summary of Organic MCM Limitations and Benefits

- Sparse sweeping capabilities for the MH-60S
- Organic MCM requires reduced force protection requirements
- Organic systems provide a limited punch through MCM capability
- Organic assets are embedded with forces at sea
- Rapid response for early situational awareness
- Networked to force commanders through C4ISR capability
- The Joint Force is enabled to conduct simultaneous warfare operations
- Enemy area denial capabilities are dismantled with reduced risk
- Reduced percent of combat power
- Reduced replacement cost of off board systems
- The enemy's ISR and targeting problems become more complex
- Higher staying power in the littoral is achieved
- Enhanced covert and clandestine operations[55]

Several of these operational constraints such as limited basing options, mine clearance capability, and data transfer constraints for the present dedicated MH-53E will be resolved by planned upgrades to the MH-53E or, in the case of basing constraints, by fleet introduction of the organic MH-60S. These airborne MCM helicopters have significant vulnerabilities. They are particularly vulnerable to attack because they are constrained in maneuverability when towing. They must sometimes operate within easy range of well-hidden shore-based, hostile units. When towing they are constrained to a fixed altitude and speed, forming an easy target for even rudimentary surface-to-air weapons. The general trend toward naval operations in littoral waters suggests that current and future

[55] National Research Council of the National Academies (2005). *Autonomous Vehicles in Support of Naval Operations* National Academies Press, Washington, D.C.

helicopters for airborne MCM will be increasingly subject to attack by hostile aircraft, helicopters, small craft, and shore-based anti-aircraft units equipped to fire heat-seeking or radio frequency homing missiles. [56]

E. CHAPTER SUMMARY

The deadly threat posed by mines exists whether or not hostilities have ceased. While armies move inland and surface combatants sail to other shores, minesweepers often remain in a theater of operations to ensure that a port or beachhead remains clear of mines to allow follow-on support for the flow of ground troops. As a result, minesweepers are often the first and last ships to operate in a given area. In at least two cases during World War II minesweepers were the first and last ships sunk in a campaign. Such is the great threat of mine warfare that the mere suspicion of the presence of mines is often all that is required to limit naval operations. At present, the U.S. Navy has two options if a mine threat is encountered while it is attempting to project power in the littoral regions of the world. The U.S. Navy can equip its surface combatants with MCM capabilities or it can summon its dedicated MCM forces and personnel. However, both of these options have limitations. If mines are laid in large numbers and types, fleet assets equipped with limited MCM capabilities may not be sufficient to neutralize the threat. If dedicated MCM forces are then required they must be mobilized and deployed from the continental United States or pre-deployed because they do not have the ability to operate organically with the battleforce. Thus, timely and effective MCM operations could be the key to the success of an operation from the sea. Based on these considerations the U.S. Navy requires dedicated MCM forces that are able to operate forward-deployed and organically with the battleforce.[57]

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[56] Committee for Naval Warfare Assessment Naval Study Board, Division on Engineering and Physical Science National research Council (2001). *Operational and Technical Challenges for Naval Forces*. National Academy Press Washington, D.C.

[57] Mathew McCarton (2000). *One Hundred Years of Sweeping: A historic Review of the Efficacy of Organic to the Battleforce Mine Countermeasures* Government Printing Office, Washington, D.C.

With the introduction of organic MCM into the Fleet, these seven new systems must be integrated into a diverse fleet of ships and sailors. The impact on readiness should be as minimal as possible. It is imperative that these systems share a common systems architecture that accounts realistically for differences between the new technology and the existing systems and facilitates their integration. It is not as clear, however, that the new systems have been considered within the constraints implied by the other organic systems. An overall MCM systems architecture is needed to ensure that common standards are adopted, or that different standards applied to various systems will not impede the interoperability of the overall MCM system-of-systems. The MCM architecture should ensure the utilization of common components and subsystems such as displays, data formats, commands, operating procedures, maintenance, storage, and spares. It should establish the formats, rates, quantity, and quality of data as well as the interfaces between various communication systems that transfer the data to established databases. [58]

Many plans focus on building block like doctrine, organization, and technology. Although necessary, these elements leave out one critical element, how the blocks are put together. In a networked force it is more important than ever to ensure proper coordination and timely integration of assets. Transformation involves various building blocks and different ways of combining them. Choosing between incremental or revolutionary approach is not the right framework for managing transformation. Systems integration, linking separate parts of an organization so weaker ones do not limit improving one, is key. Since the armed forces are moving towards a more networked operation, this approach can be applied throughout the defense and intelligence communities from the highest level to the lowest.[59]

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[58] Committee for Naval Warfare Assessment Naval Study Board, Division on Engineering and Physical Science National research Council (2001). *Operational and Technical Challenges for Naval Forces*. National Academy Press Washington, D.C.

[59] Paul Bracken, (2004, October). Systems Integration and the New American Way of War. *Joint Forces Quarterly Issue, 35,* 123-128.

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III. TRANSITIONING TO FUTURE MIW CONOPS

A. INTRODUCTION

Today's DoD acquisition community measures success based on meeting cost, schedule and performance goals. The DoD differs from the commercial industry based on its determination of success. The commercial industry measures success based on profit, where the DoD ultimately measures success based on its ability to win wars. There are any number of external factors that affect the process of DoD systems development, which includes the Planning Programming Budgeting System (PPBS), and to a lesser extent the political climate. Although commercial projects have their own fiscal constraints and consumer environment to contend with, products developed in the commercial realm are less affected by their planned budget and consumer environment. In addition to external factors, the DoD tends to concentrate its efforts based on advances in technology, where many commercial industries minimize risks by relying on mature, stable and proven technologies.

Successful DoD management of cost, schedule, and performance risks is tied to the ability of a program's team to fully attain knowledge about key dimensions of the product under development. Knowledge means that program managers and decision makers have reached virtual certainty about all aspects of the product being developed, such as critical manufacturing processes. In essence, knowledge is the inverse of risk. Regardless of the product being developed, at some point in the process the program team attains full knowledge about all aspects of that product. Commercial teams achieve this knowledge earlier than their DoD counterparts. Levels of knowledge that most significantly affect program outcomes converge at three critical points: the first being when a match is made between the customer's requirements and available technology, second when the product's design is determined to be capable of meeting performance requirements and finally when the product is determined to be producible within cost, schedule, and quality targets.[60]

Contrary to commercial best practices and development philosophy to attain all aspects of knowledge before design, Steve Jobs, Apple's Chief Executive Officer (CEO) embraced risk by taking a completely different approach with the development of Apple's newest product lines. "New things don't want to be born", says Jobs. Innovation causes problems, and it's much easier simply to avoid it. Apple employees talk incessantly about what they call "deep collaboration" or "cross-pollination" or "concurrent engineering." Essentially, it means that products don't pass from team to team; there isn't a discrete, sequential development stages for product subsystems. Product development instead, is simultaneous and organic. Products get worked on in parallel by all departments at once: design, hardware and software in endless rounds of interdisciplinary design reviews. When the challenges are that complex, you have to develop a product in a more collaborative, integrated way.[61]

Although Apple's CEO cites prudent observations regarding problems associated with creativity and product development, he demands innovation to a level uncommon in commercial industry. Jobs' approach to innovation has allowed Apple to be deeply rooted as a world-wide commercial power house. This already established company has expanded its niche market for Apple Macintosh computers, their software operating system and has introduced its newest products, the iPod and Apples' iTunes. These products have spanned the globe and crossed boundaries to include personal computer users as well as traditional Apple users. The world-wide acceptance of these products is based primarily on two key elements; compatibility and ease of use. This seemingly

[60] K. Schnasi, P. Francis, M. Sullivan, M. Bonner, B. Luby, M. Santos, et al. (2000). Applying Best Practices to Weapon Systems Takes the Right Environment. *Program Managers Guide* (January-February).

[61] Lev Grossman, (2005, October) What's Next How Apple Does It. *Time Canada,* 166 No. 17.

simple innovation has been integrated across various product lines with relatively simple and straight forward human systems interface. The iPod has been integrated as a personal portable stereo and digital data storage device to a seamlessly integrated portable jukebox for your vehicle that is smaller than the size of a pack of cigarettes.

Similar to Apple's approach, the DoD looks to innovative design to achieve superiority on the battlefield. Currently, there is a tendency to concentrate on the mechanisms that various systems use to interoperate. However, focusing solely on mechanisms misses a larger problem. Creating and maintaining interoperable systems-of-systems requires interoperation not only at the mechanistic level, but also at the levels of system construction and program management. Improved interoperation will not happen by accident and will require changes at many levels. Interoperability is a difficult challenge. This is true whether the goal is to increase interoperability between systems that originally did not interact, or to build new systems designed to interoperate. Unfortunately, very little is known about interoperability requirements at the start of a program. In some cases, the systems that will interoperate are not yet conceived. This approach to product development is contrary to exercising commercial best practices and attainment of all aspects of knowledge. Thus, new strategies must be developed to anticipate future needs and cope with current uncertainty. In other cases, the constraints imposed by existing systems make approaches to achieving interoperability equally complex.[62]

Getting better outcomes on weapon system programs will take more than attempting to graft commercial best practices onto the existing acquisition process. There are underlying reasons and incentives for why such practices are not a natural part of how weapon systems are bought. Environmental factors, such as the intense competition for funding when a program is launched, encourage lower standards of knowledge and the acceptance of higher, but

[62] E. Morris, L. Levine, C. Meyers, P. Price, D. Plakosh, (2004). *System of Systems Interoperability (SOSI* (CMU/SEI-2004-TR-004). Washington, D.C.; Government Printing Office.

unrecognized, risks. For an acquisition process to meet DoD's goal of developing and producing militarily superior weapons in a resource-constrained environment, you must ask the basic question of how a capability can best be provided to the customer. The characteristics of best practices suggest a process for developing new capabilities, whether they are commercial or defense products, which are based on knowledge. It is a process in which technology development and product development are treated differently and managed separately. The process of developing technology culminates in discovery and must, by its nature, allow room for unexpected results and delays, contrary to the DoD's schedule driven process.

The process of developing a product culminates in delivery, and therefore, gives great weight to design and production. A knowledge-based process is essential to getting better cost, schedule, and performance outcomes. This means that decision makers must have virtual certainty about critical facets of the product under development when needed. Such knowledge is the inverse of risk. Most commercial and military programs do not follow the same processes in their development cycles. However, at some point, full knowledge is attained about a completed product, regardless of what development approach was taken.[63]

Although the DoD's desired approach to system innovation aligns with Jobs' philosophy and attempts to achieve similar outcomes, the environment under which the DoD functions tends to limit its ability to accurately model the Apple paradigm. Innovative design provides an ability to achieve a superior fighting force, but that same innovative drive increases risk for cost, schedule and performance requirements. In an attempt to achieve the best of both commercial and the DoD systems acquisition, having a clear understanding of system requirements is central to the satisfaction of the customer, or in this case to sustain a war fighting superiority second to none.

[63] General Accounting Office (1999, March 19) Best Commercial Practices Can Improve Program Outcomes. Washington D.C. Government Printing Office.

B. LINKING FUTURE MIW REQUIREMENTS WITH DESIGN

Accelerating rates of change will make the future environment more unpredictable and less stable, presenting our Armed Forces with a wide range of plausible futures. Whatever direction global change ultimately takes, it will affect how we think about and conduct joint and multinational operations in the 21st century. How we respond to dynamic changes concerning potential adversaries, technological advances and their implications, and the emerging importance for information superiority will dramatically impact how well our Armed Forces can perform its duties in 2010. Most importantly, these active and passive measures will be combined to provide a more seamless joint architecture for force protection, which will leverage the contributions of individual services, systems, and echelons. The result will be improved freedom of action for friendly forces, and better protection at all echelons against precision attack, weapons of mass destruction, and other conventional or non-conventional systems.[64]

At the operational level, mine warfare's layered defense architecture, as articulated in *Joint Vision 2010*, is extended to provide theater-wide defense and full-dimensional protection for operating forces during periods of peace and conflict. At the theater level, forward-based supporting MCM forces are available during peacetime periods to augment strategic-level bottom mapping and survey operations, and during conflict to quickly move to engage mines that have been laid. Additionally, theater and strategic systems and organizations combine to provide C4ISR and environmental data to support MIW. During periods of rising tensions or conflict, theater mine defense draws from all joint force MIW resources to reduce the mine threat, including preemptive countermining and Maritime Interdiction Operations to prevent mining. In cases where self-protection is not an issue, forward deployed supporting MCM forces can conduct extensive advance operations prior to the arrival of other operational forces.

[64] Chairman of The Joint Chief of Staff, (2000) Joint Vision 2010 America's Military: Preparing for Tomorrow, Washington, D.C.

Each of these activities has considerable implications for linking organic and dedicated MIW forces and organizations. As always, connectivity is an important element to overall MIW success.[65]

Although tomorrow's next generation systems are being developed as separate and distinct programs, their individual design and functionality are linked to an overall MIW capability that is tied to tomorrow's strategic vision. As illustrated above and throughout this study, the sea mine threat varies with depth, actuation, lethality, and complexity. There is no one solution to counter the variety of sea mines in all environments. Tomorrow's next generation systems-of-systems along with dedicated and proven technologies will collectively provide a capability beyond today's MCM fighting force.

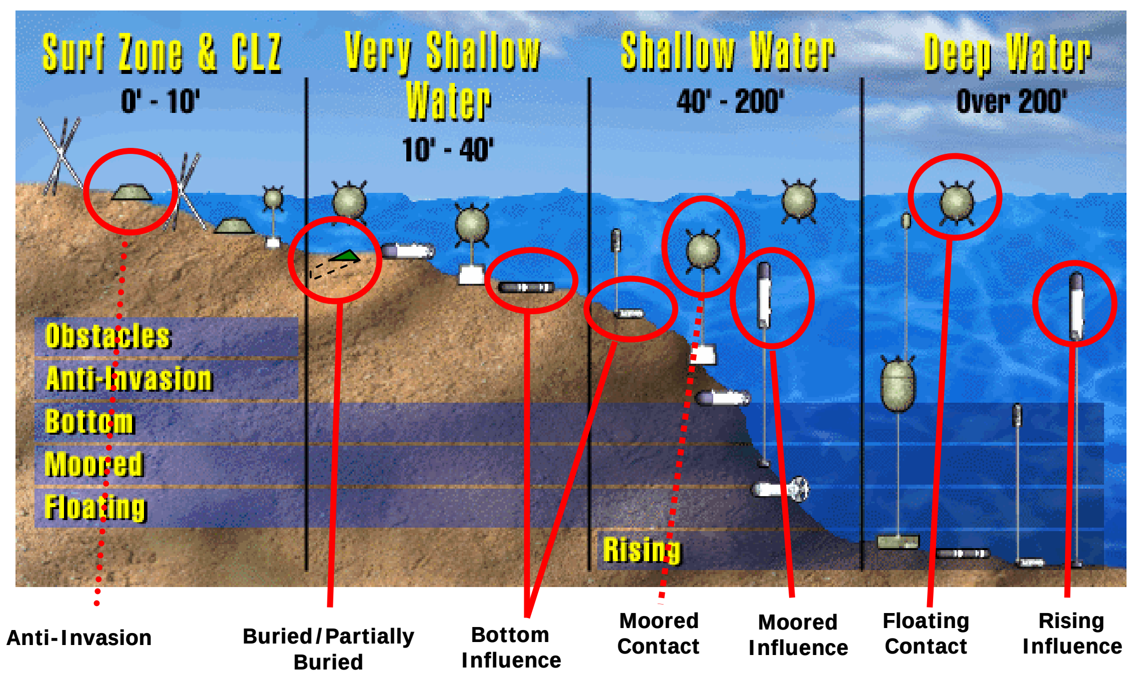

Figure 14. Mine Threat Environment[66]

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[65] ADM Jay Johnson, GEN James Jones, (2000). *U.S. Naval Mine Warfare Plan, Fourth Edition Program for the New Millennium* Department of the Navy, Washington, D.C.

[66] Capt Vito Jimenez (2002) Airborne Mine Counter Measures [Graphic Image], Program Executive Office Littoral Mine Warfare. Washington, D.C.

The DoD has fully embraced the ideology of interoperability, innovation and commercial best practices as discussed in publications such as the *Program Managers Guide*, *Acquisition Reform and Joint Forces Quarterly.* This new approach to weapon systems development has been further supported by official correspondence such as the *Instruction for Modular Open Systems Architecture* from the Secretary of Defense. As previously mentioned, plans that focus exclusively on the building blocks such as doctrine, organization, and technology are leaving out one critical element; specifically how the blocks are put together. The spirit behind many of the DoD's future visions such as: Transformation, Sea Power 21 and Acquisition Reform are linked by one premise: a capabilities based fighting force to counter an asymmetric threat. The framework behind MOSA can serve as the roadmap for tomorrow's transformation of the DoD system-of-systems development.

C. ESTABLISHING A FRAMEWORK FOR THE FUTURE

The application of MOSA is consistent with sound system engineering principles; however, it requires a different mindset as the systems engineering process is executed during the design of a system and then repeated throughout the life-cycle of that system. Characterized by modular design, key interfaces, and the use of open standards for key interfaces where appropriate, MOSA is focused on a system design that is modular, has well defined interfaces, is designed for change and, to the extent possible, utilizes widely supported industry standards for key interfaces.

Systems engineering controls are used to track decisions and requirements, maintain technical baselines, manage interfaces, manage risks, track cost and schedule, track technical performance, verify requirements are met, review and audit the development progress. During the systems engineering process, architectures are generated to better describe and understand the system. The word "architecture" is used in various contexts in the general field of engineering. It is used as a general description of how the subsystems join together to form the system.[67]

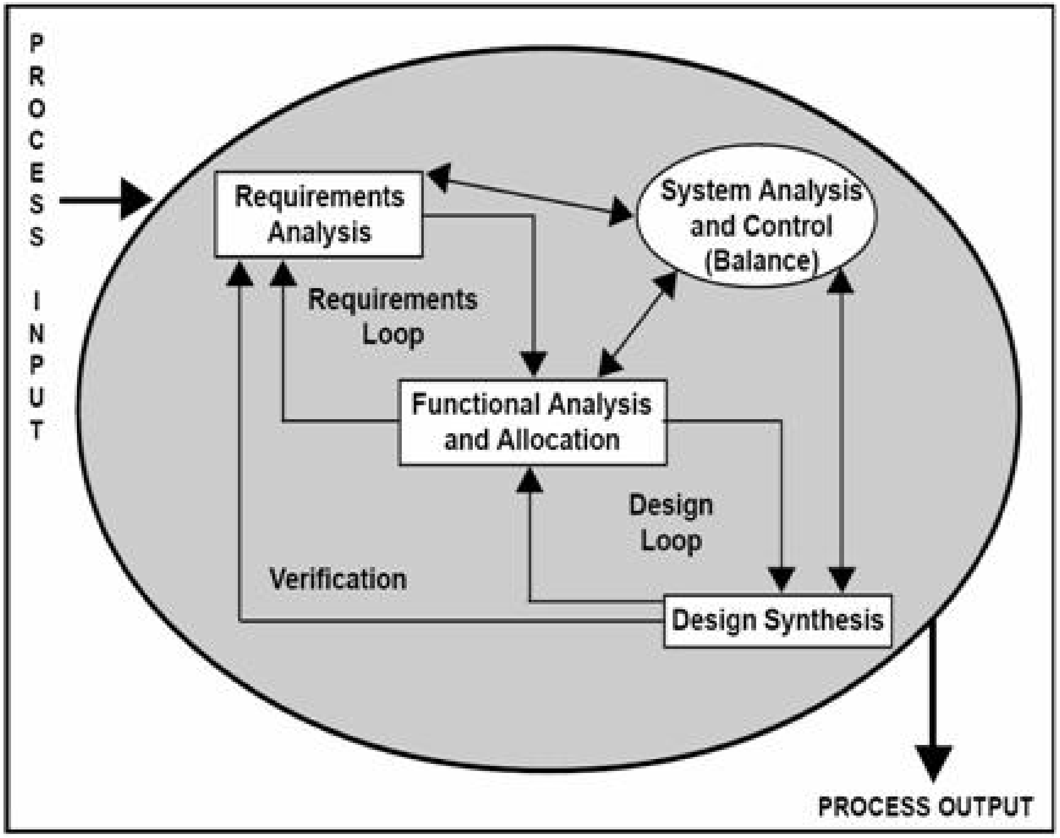

Figure 15. Systems Engineering Process[68]

Partitioning a system appropriately during the design process to isolate functionality makes the system easier to develop, maintain, and modify or upgrade. Given a system designed for modularity, functions that change rapidly or evolve over time can be upgraded and changed with minor impact to the remainder of the system. This occurs when the design process starts with modularity and future evolution as an objective. The focus of MOSA is not on control and management of all the interfaces within and between systems. It will

[67] Defense Acquisition University (2001). *Systems Engineering Fundamentals.* Defense Acquisition University Press, Fort Belvoir, VA.

[68] Defense Acquisition University (2001). *Systems Engineering Fundamentals.* [Graphic Image] (p. 6), Defense Acquisition University Press, Fort Belvoir, VA.

be very costly and perhaps impractical to manage hundreds and in some cases thousands of interfaces used within and among systems. MOSA manages the interfaces by grouping them into key and non-key interfaces. It distinguishes among interfaces that are between technologically stable and volatile modules, between highly reliable and more frequently failing modules, and between modules with least interoperability impact and those that pass vital interoperability information. Key interfaces should utilize open standards in order to produce the largest life-cycle cost benefits.[69]

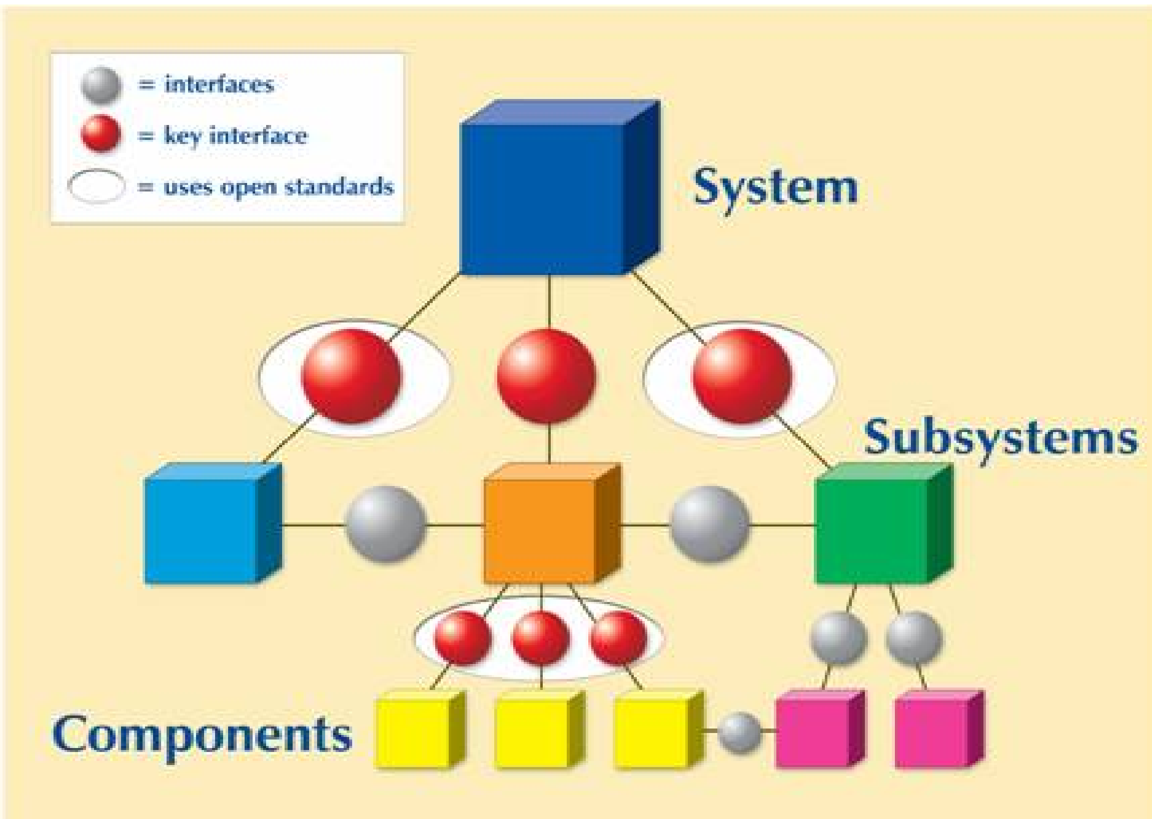

Figure 16. MOSA Key Interfaces[70]

[69] Open Systems Joint Task Force. (2004). Program Manager's Guide, *A Modular Open Systems Approach (MOSA) to Acquisition,* (Version 1.2). Washington, D.C. Government Printing Office.

[70] Open Systems Joint Task Force. (2004). Program Manager's Guide [Graphic Image], *A Modular Open Systems Approach (MOSA) to Acquisition,* (Version 1.2). Washington, D.C. Government Printing Office.

As previous illustrated, naval MCM programs employ a mix of mine field ISR, hunting, neutralization and sweeping which constitute a capability through a multi-disciplined system-of-systems. Collectively the resulting capabilities, together with support from C4ISR systems and MEDAL data connectivity are intended to provide U.S. Naval Forces with open-ocean and littoral minefield maneuverability with an acceptable level of risk.

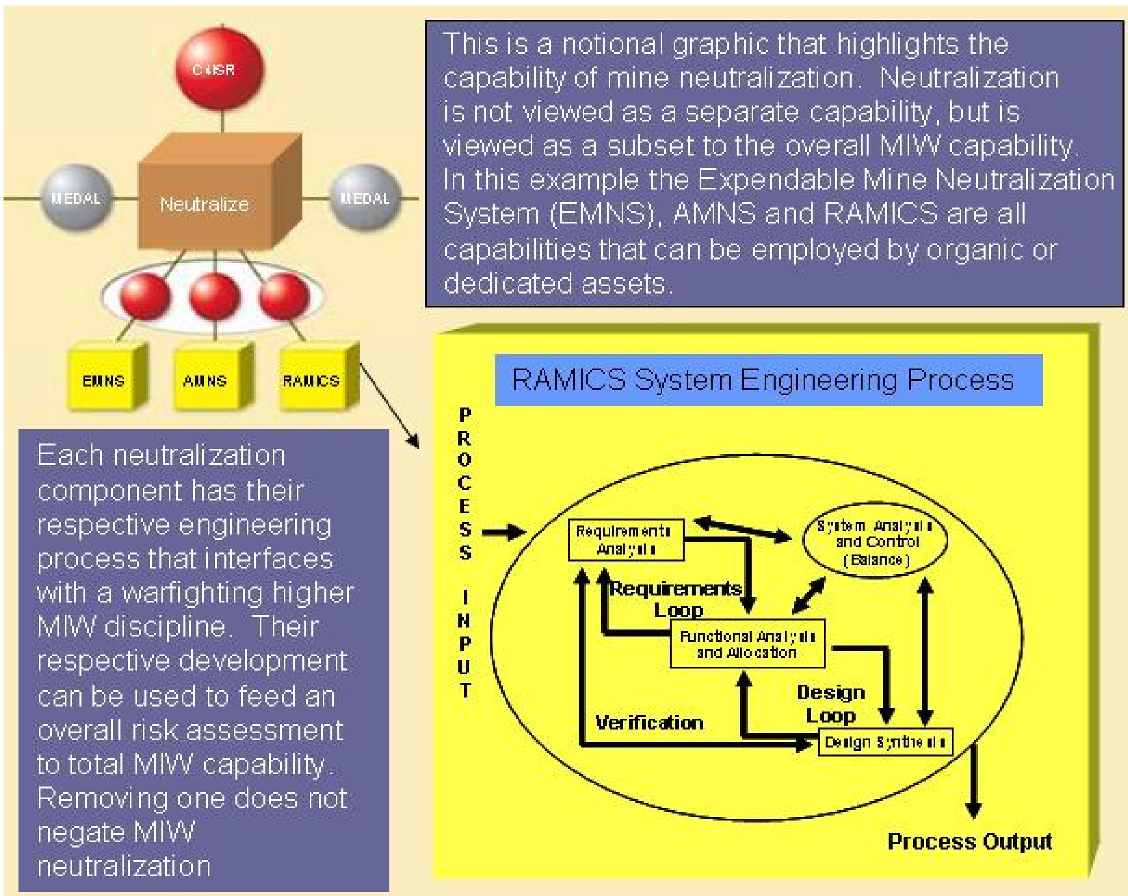

Figure 17. Excerpt of MIW Architectural Framework

Expanding the above notional architecture to include all MIW disciplines will provide a framework for engineers and Program Managers to view tomorrow's MIW system-of-systems not as stove piped individual innovations, but as a complete framework to focus the development of a war fighting capability. Additionally, best business and commercial practices, such as *Balanced Score Card* and, or risk and decision aid software such as *Palisade Precision Tree*

Analysis may be incorporated to ensure that established metrics and risk management plans can be monitored to provide an overall risk assessment to planned capabilities.

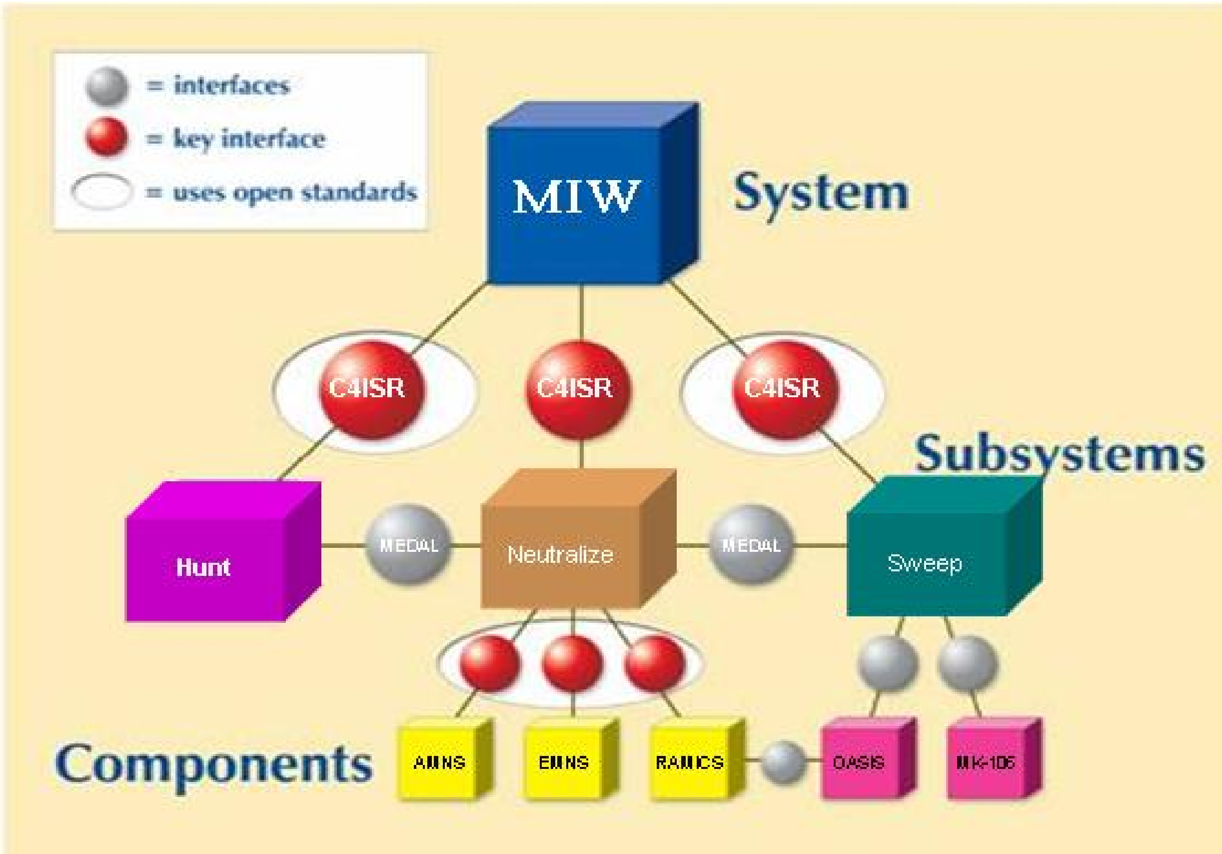

Figure 18. Notional Future MIW Capabilities Architecture

1. Science and Technology Prospective

In February 1999 the Naval Research Advisory Committee was tasked by the Assistant Secretary of the Navy for Research, Development and Acquisition, to conduct a study to determine the application of unmanned vehicles (UV's) in MCM operations and to identify alternatives. The tasking included a review of current programs under development, with a view toward determining gaps and overlaps. Based on the findings, the study was to make recommendations for future UV requirements. Technology and system demonstrations need to be carried out in a context that is increasingly realistic about the threat and environment, as well as about appropriate time lines. It is fair to say that limitations of the state-of-the-art in vehicles, sensors, computation, communications and navigation preclude the effective use of unmanned vehicles from the very shallow to surf zone. No current or near-term unmanned vehicle capability for underwater communications and precise navigation exists for the surf zone. Recently initiated science and technology programs offer opportunities for future demonstrations and transitions in the surf zone to very shallow water.[71]

2. Limitations of Tomorrow's Next Generation Systems

Unfortunately, mine hunting is not effective in 60 percent of the littoral regions near potential adversaries. Sea access to these areas requires minesweeping. Currently, the MH-53E and the MK-106 sled, or the MH-60S with the developmental OASIS system, are needed to meet world-wide operation plans for minesweeping. Many of the same technologies that are driving the improvements in mine hunting could be leveraged in an effort to develop an unmanned minesweeping system. A desire to keep the man out of the very shallow minefield makes unmanned minesweeping systems an attractive option. Unmanned systems are the minesweepers and hunters of the future. The Deputy Assistant Secretary of the Navy for Mine and Undersea Warfare, Dale Gerry, during his brief at the fourth international symposium on technology and the mine problem, stated:

> We are looking to you to help fill our capability gaps. Our number one priority is to be able to get from the 40 foot water depth, through the surf, to the beach exit zone in order to get our Marines ashore. We still have the age-old problem of countering buried and pressure mines.[72]

[71] Naval Research Advisory Committee. (2000). Unmanned Vehicles (UV) In Mine Countermeasures, Washington, D.C., Government Printing Office.

[72] Dale Gerry (2000, March 12). [Address]. Address presented at the Naval Postgraduate School. Monterey, CA. [Transcript]. Retrieved June 16, 2006 from: http://www.demine.org/meetings/Mar2000/Gerry.html.

Operating in the very shallow water and surf zone, 40 feet or less makes underwater communications more difficult and variable. As operations move onto the beach where ground robotics might be applicable, these systems remain to be proven, particularly given the threat posed by buried mines and obstacles. Precise underwater navigation must be achieved in all depths, and data fusion for a common tactical picture must be achieved. Assured neutralization remains a high-end challenge. Finally, as history will reflect, the ability to reduce the size and cost of the vehicles and their sensors while increasing reliability and capability will most likely be the greatest challenge.[73]

D. REQUIREMENTS TRACEABILITY

To ensure that affordable, technically achievable requirements are attained, the MIW program demanded an immediate focus on systems engineering and requirements traceability. As a system-of-systems, the above notional MIW architecture will depend heavily on system maturation and interoperability. To provide a capability to the user as rapidly as possible, the DoD has adopted spiral development principles. Initial fleet introduction for the most mature of the newly designed next generation systems was planned for a 2005 delivery, but as a result of unforeseen developmental barriers, fleet introduction was delayed by two years for some systems and as much as four years for less mature technologies. Spiral development in conjunction with requirements traceability can be used to manage developmental and capability based risks as well as providing the end user a capability, rather than delivering a fully mature system much late. Unlike some new acquisition programs, MIW systems requirements were already defined by a need to recapitalize current capabilities, rather than to develop new war fighting functions. Establishing a systems architectural process that seamlessly links requirements from capabilities documents to performance specifications of war fighting needs can be captured by creating an MIW requirements traceability matrix.

[73] Naval Research Advisory Committee, (2000). Unmanned Vehicles (UV) In Mine Countermeasures, Washington, D.C., Government Printing Office.

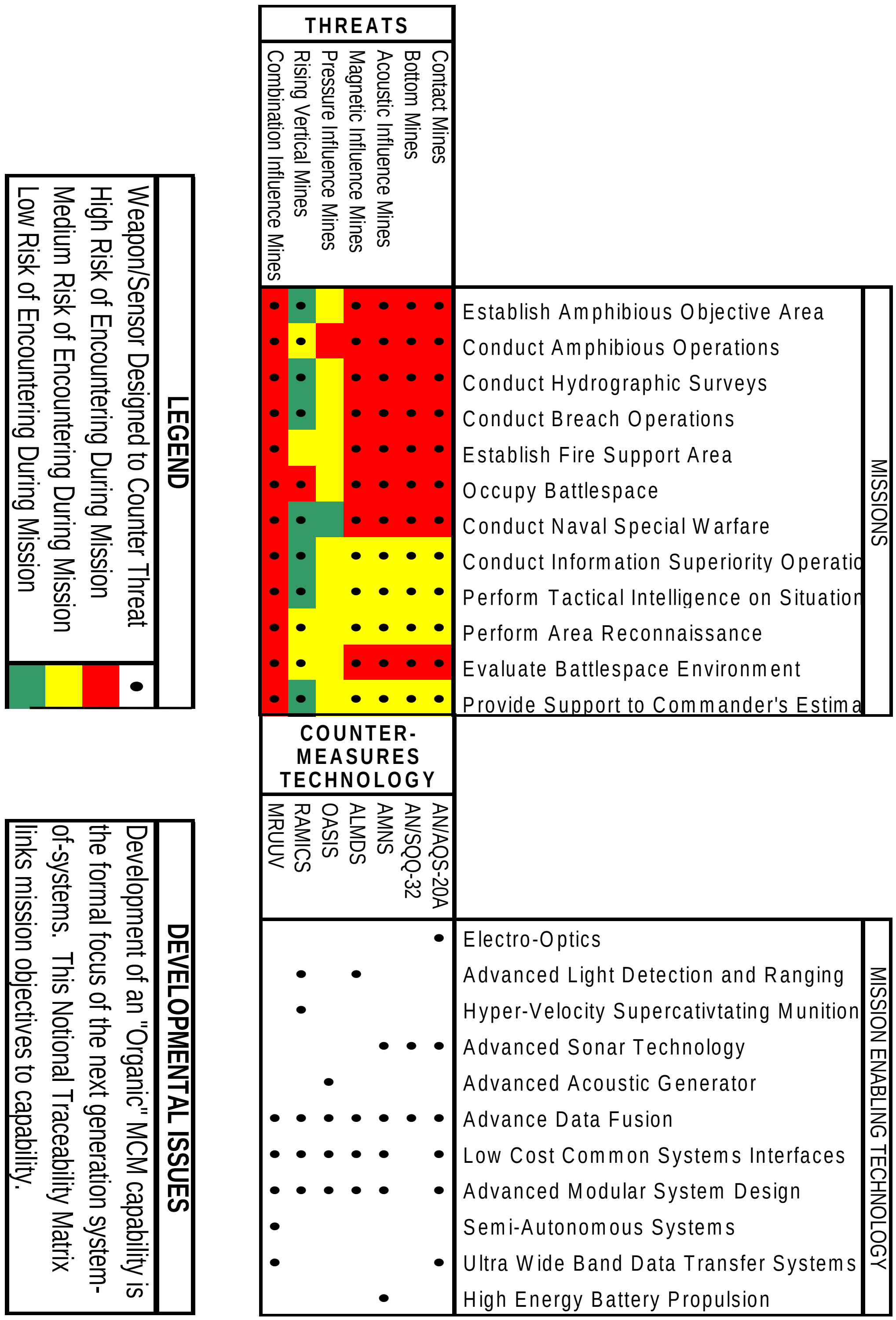

Table 2. Notional MIW Traceability Matrix[74]

[74] Naval Research Advisory Committee, (2005, October 4). *Science and Technology for Naval Warfare, 2015-2020.* [Graphic Image] Image derived from p. 4 of presentation. Washington, D.C.

E. FORM FOLLOWS FUNCTION

There are significant risks and costs associated with using expensive, high-end, power projection platforms against the enemy's fairly inexpensive air, surface, and undersea platforms with their associated combat and information technologies. Declining force numbers further impair the ability of our capital ships to perform additional access missions. Further, it is unlikely that, in the foreseeable future, U.S. Naval Forces will be able to afford the numbers of multi-mission high end ships it would take to fill the gaps in needed littoral capabilities. LCS will contribute to SEA SHIELD through its unique capability to respond quickly, to operate in the littoral environment, and to conduct focused missions with a variety of networked off board systems. Approximately 60 percent of the missions conducted by ships are mobility related missions. The current practice of using multi-mission combatant ships to conduct mobility missions because of a lack of alternatives has consequences of high operating costs, increased operational and personnel tempo, high maintenance expense of complex units, and reduced availability and readiness for combat-associated missions. With modularity and open architecture, LCS has an inherent capability to remove the MIW, SUW and ASW mission modules, freeing up space and weight capacity to support a host of other non-access missions.[75]

The littoral battlespace requires focused capabilities in greater numbers to assure access against asymmetrical threats. The LCS is envisioned to be a networked, agile, stealthy surface combatant capable of defeating anti-access and asymmetric threats in the littorals. It will have the capability to deploy independently to overseas littoral regions, remain on station for extended periods of time either with a ships at sea or through a forward-basing arrangement. It will operate with Carrier and Expeditionary Strike Groups, in groups of other similar ships, or independently for diplomatic and presence missions. Additionally, it will have the capability to operate cooperatively with the U.S. Coast Guard and

[75] Navy Warfare Development Command, (2003, February). *Littoral Combat Ship Concept of Operations,* Version 3.1, Government Printing Office, Washington, D.C.

Allies. The LCS will rely heavily on manned and unmanned vehicles to execute assigned missions and operate as part of a netted, distributed force. In order to conduct successful combat operations in an adverse littoral environment, it will employ technologically advanced weapons, sensors, data fusion, C4ISR, propulsion, optimal manning concepts, smart control systems and self-defense systems. The LCS will be the Navy's most innovative, modularized and reconfigurable ship capable of being reconfigured into any one of three different warfare packages within a day's time. The MIW module includes the RMS; the AN/AQS-20A sonar mine detecting system; OASIS; ALMDS; RAMICS and the AMNS. At the heart of the ASW module is the Advanced Deployable System. This system is a bottom array that may be deployed from the LCS at high speeds, providing high-quality acoustic surveillance data. Additionally, the ASW module includes acoustic sensors such as a multifunction towed array, and a remote towed active source, along with other detection systems and weapons designed for use aboard the MH-60R helicopter and unmanned surface vessels. The SUW module includes weapons such as a 30mm cannon, the same as is used in the RAMICS.[76]

The key to the successful integration of the five OAMCM systems is a roll-on, roll-off mission kit consisting of the MH-60S Common Console; the Carriage Stream Tow and Recovery System (CSTRS); and the Tactical Common Data Link (TCDL). The Common Console is common to all five OAMCM systems as well as the other MH-60S missions and provides for control, monitor and display of the OAMCM system. CSTRS is a modular device that will provide the capability to carry and deploy all five of the AMCM systems. TCDL will provide a high-bandwidth, near-real time sensor data link with a relay capability to pass data to the Mine Warfare Commander. Both the MH-60S and LCS bring a level of commonality and integration unprecedented in naval systems design. Both vehicles are designed and formed to function in tomorrow's war fighting vision.

[76] Program Executive Office Ships, (2006). What is LCS, Retrieved July, 20 2006 from http://peos.crane.navy.mil/lcs/program.htm.

F. CHAPTER SUMMARY

Innovative design has the potential of bringing unprecedented capability to the end user. As illustrated in this study, the Apple Corporation has experienced the success of an innovative, modular and adaptable design. Innovation has increased the U.S. DoD's war fighting superiority and is unmatched by it closest rival. Although the DoD attempts to align its acquisition process with that of successful commercial best practices, its need for innovative design contradicts the risk mitigation philosophy of attaining full knowledge of a system early in development. This contradiction manifests itself in risks of unstable funding, system capability and, or potentially a delayed capability to war fighters in the field.

The five organic airborne, two unmanned semi-autonomous systems and a netted data fusion infrastructure along with dedicated MCM units constitute tomorrow's MIW capability. All of the newly designed MIW systems, as well as upgrades to existing MCM programs where conceived at different times, individually provide different capabilities, and have various fielding timelines. Uniting these individual programs yields an MIW capability far superior to the pre-Cold War era. Linking these capabilities together under MOSA's architectural framework provides a focused overarching management program that will minimize performance, cost and schedule risks. As illustrated in the notional architecture, modularity provides a view to the overall MIW capability while simultaneously illustrating sub-components. Removal of one sub-system does not negate the overall capability, and adding potential components have the potential for mitigating risk.

Although uniting the system-of-systems under one framework reduces risk, linking them through the use of a requirements traceability matrix is crucial to managing the developmental as well as capabilities risks while conducting current and future MCM operations. The notional architectural framework along with the traceability matrix was designed to providing a forward and backward compatibility with user requirements, war fighting capability and systems development.

These tools have been developed to provide the best means of meeting MIW product development as well as other war fighting disciplines within the DoD. The use of these tools, although crucial to MIW weapon systems development, is just a small part of the overall development plan. Another very crucial and intangible portion of the program's architecture centers on commitment. It will take commitment from key stakeholders as well as members external to the development process to achieve a viable MIW capability. In the conduct of this research it was readily apparent that a number of best practices are currently being utilized by DoD Program Offices and defense contractors. These practices include tools such as Risk Management, the use of commercial off the shelf components, modeling and simulation early in program development, Lean, Six Sigma, Balanced Score Card, the use of traceability matrixes as well as numerous checks and balances throughout life cycle of various programs.

Identifying military product development as purely an internal institution to the Defense Department would be a mischaracterization. Many external factors can present a negative effect on product development. These items include the congressional PPBS cycle, lobbyist vying for production in his or her State or district, P3I initiatives, evolving requirements as well as technology insertion. Chapter IV will conclude this research and examine how these influences have affected the development of tomorrow's MIW system-of-systems and provide recommendations to limit their effect on system development.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

Mine countermeasures is a uniquely singular naval warfare discipline. Its capabilities have the potential of providing the means to reduce, if not mitigate the risk of encountering the threat of sea mines in the open-oceans and the world's littorals. To that end, MCM operations are a crucial tenet to current and future war fighting visions for the DoD. Managing risks associated with the mine threat provides assured access for U.S. Naval Forces and extends to other U.S., and allied forces. It has been noted throughout this study that the threat of sea mines are a force multiplier that has been in use since the days of the American Civil War. This threat over time has increased in complexity and lethality. Keeping pace with this simple but deadly threat has been a difficult task to counter for the DoD.

Sea mines have sunk many U.S. Navy ships, including minesweepers, and killed many sailors throughout history. At least sixty-five ships and small craft were sunk by German and Japanese mines in World War II. Mines were responsible for seventy percent of all casualties suffered by the U.S. Navy in the first two years of the Korean War. They were also responsible for the sinking of all five ships lost by the U.S. Navy during that conflict. With enough planning, time, and ships, an amphibious assault can be successful no matter how many enemy mines are present, but this comes at a cost. The price paid comes in large numbers of lives and valuable assets. Today, the American public and especially the media have come to view even small setbacks in military operations negatively. To reduce the loss of life and valued assets, the U.S. Navy has embarked on improving its MIW capabilities.[77] These capabilities

[77] Mathew McCarton (2000). *One Hundred Years of Sweeping: A Historic Review of the Efficacy of Organic to the Battleforce Mine Countermeasures* Government Printing Office, Washington, D.C.

come in a multi-faceted form; weapons, sensor systems, data gathering and fusion systems that are designed to travel with strike groups, or are forward-deployed to rapidly address the mine threat.

As the post-Cold War era shifts the focus of assured access to the world's open-oceans and littorals, many new challenges presented by non-traditional foes bring to light an anti-access threat from asymmetric adversaries. While the anti-access challenge is a problem for all joint forces, naval forces have traditionally played a major role in preserving U.S. freedom of action when forward bases have been unavailable. They have also made important contributions to theater break-in operations. As a result, the Navy and Marine Corps are likely to play an increasingly important role in power projection operations in the 21st century. The challenge of taking on anti-access networks in general, and naval anti-access networks in particular, is an especially critical one for fleet planners. For the Navy and Marine Corps to be successful in a high-stakes operational competition against emerging anti-access networks, the 21st century fleet will need enhanced, thoroughly integrated and networked defensive, strike, maneuver, mine warfare, and support capabilities.[78]

Historically the sense of urgency created by encountering enemy mining campaigns has not been lasting. Eventually, the need to maintain a highly responsive MCM capability was largely forgotten at various points throughout U.S. Naval history. To avoid the possibility of having freedom of maneuver and projection of power ashore curtailed, the U.S. Navy should possess a dedicated and organic battleforce MCM capability.[79] Notwithstanding the contributions maritime MCM capabilities bring to strategic military operations, having a robust countermining capability also has a definitive effect on the world's economy. The structure of foreign relations between sovereign nations tends to dictate choices

[78] Col. Robert O. Work, (2002). *The Challenge of Maritime Transformation: Is Bigger Better*. Center for Strategic and Budgetary Assessment, Washington, D.C.

[79] Mathew McCarton (2000). *One Hundred Years of Sweeping: A Historic Review of the Efficacy of Organic to the Battleforce Mine Countermeasures* Government Printing Office, Washington, D.C.

that would level the playing field. In the past, this international behavior has often taken the form of “balancing” as states pursue security and economic strategies designed to enhance their survival and influence in an anarchic world. There is no reason to believe that the world’s globalization system would change this basic behavior of sovereign nation’s attempts to maintain a level playing field. Within the dynamics of globalization the U.S. will be unable to “rest on past laurels” without forfeiting its global leadership role. One key aspect of the future would entail the continued pursuit of the U.S. policies of proactive international engagement and global military superiority to reinforce the positives of globalization.[80]

Indirectly, Sailors and Marines have a significant effect on the world’s economy and will be instrumental to the U.S. DoD transformation initiatives. Historically, both the Navy and Marine Corps embody the culture that will be at the heart of the future naval force. However, the environment in which our Sailors, Marines, civilians, and contactors must operate has changed significantly since the all-volunteer military force was established thirty years ago, when the world was in the grips of the Cold War. Today, threats to safety and security come from multiple directions, often in diffused and difficult to predict ways. As the geopolitical ground shifts in ways not before imagined, being agile and having the means to produce military, political, and economic opportunities in an ever changing world is crucial to stability. The post-Cold War era has ushered in a requirement to enable our MCM force to be far more agile and responsive to global mine threats than in years past.[81] The advent of tomorrow’s organic MCM systems coupled with advances to legacy MCM systems will provide a capability to meet an ever expanding threat of sea mines.

In our most recent history, key stakeholders in congress and senior military leaders have seen the need to enhance the U.S. Navy’s MCM capability

[80] CDR John Pruitt, (2000). *The Influence of Sea Power in the 21st Century,* Retrieved May 22, 2006, from: web.mit.edu/SSP/program/working.html.

[81] Gordon England, ADM Vern Clark, GEN Michael Hagee (2003) *Assured Access and Projection of Power…From the Sea:* Naval Transformation Road Map 2003. Washington, D.C.

to meet tomorrow's threat. Recognizing that the Navy's mine warfare programs are so potentially important, and recognizing that developments in this warfare area has lagged behind those in other warfare areas, the U.S. Navy's interest in MIW has taken a strong turn upward. Naval Leaders were directed by the Chief of Naval Operations to ensure that MCM forces receive much more attention and become organic to battle forces at sea rather than remain exclusively the domain of a separate supporting force. Although this mandate has served as the catalyst to focus a strong effort to revive this singular naval discipline, cultural and developmental barriers have slowed the push to integrate tomorrow's system-of-systems into mainstream U.S. Naval operations.

During the spring of 1999 General Krupp, Director of Expeditionary Warfare and a host of civilian and military Defense Department officials addressed an annual conference sponsored by the National Defense Industrial Association on expeditionary warfare in Panama City, Florida. During this conference, General Krupp identified that naval mine warfare programs remained woefully inadequate to meet the future needs of U.S. expeditionary forces. Senior leaders blame the problem both on shortage of funds and on a Navy culture that regards mine warfare as an unglamorous profession. General Krupp stated: "We need to be able to send sailors and Marines across the beach without fear of stepping on mines ... We can't do that now."[82] Since that conference approximately seven years ago the challenge of safely getting Marines and Sailors ashore remains an "Achilles' Heel" for the U.S. DoD. Yet since this renewed emphasis on MCM approximately seven years ago, the U.S. is not able to efficiently counter the near-term threat of sea mines. Current MCM programs have brought the U.S. closer to providing an efficient means to conduct organic mine warfare operations, but these same improvement programs have major shortcomings that are exacerbated as a result of competing for limited resources, changing requirements, and stove-piped development plans. In order

[82] Sandra I. Erwin (1999), Navy Faulted For Slow Fielding of Anti-Mine Systems, from: www.nationaldefensemagazine.org/issues/1999/Jan/Navy_Faulted.htm, Retrieved March 13, 2006.

to efficiently manage the development of tomorrow's next generation system-of-systems, a new approach to product development must be adopted. Adopting an overarching systems architecture based on MOSA principles is one way of meeting this complex development challenge.

Open systems architecture identifies components, the relationship between components, and the rules for the architecture's composition. An Open System Approach is based on an architecture that uses open standards to describe these relationships and rules. An open systems approach should facilitate the management of risks associated with the use of commercial items or non-developmental items. Although the open systems approach, through the use of open specifications and standards, serves to mitigate risks on one hand, it also carries its own unique risks. The risks associated with products implementing open systems may be varied, but potential issues such as product availability, supportability, standards conformance and configuration control may need to be addressed. The following are guidelines for consideration:

- Adopt industry consensus based standards with market research that evaluates the short and long term availability of products built to industry accepted specifications and standards
- Incorporate a disciplined systems engineering process that examines tradeoffs of performance, supportability and upgrade potential within defined cost constraint
- Use an open systems approach for weapon systems electronics that provides a foundation for lower life cycle costs and improved weapons systems performance
- Address the key considerations of interfaces, architecture, risks and supportability early
- Adopt interface management guidelines based on openness, maturity, performance, conformance and future needs
- Define and describe a system architecture that is traceable to the requirements
- Base development on modular, hierarchical and layered architecture on open standards at interfaces
- Use a cooperative process between government and industry for the selection of an architecture

- Specify key performance attributes of system building blocks including internal interface standards where necessary
- Identify aspects of the program that might limit the use of an open systems approach
- Link the architecture approach resulting from a system engineering process to a business case analysis
- Link decisions about architecture to performance, life cycle cost, schedule, and risk
- Identify opportunities for reuse of hardware and software configuration items and dependence upon interfaces
- Identify the risks to the program as a result of implementing open systems
- Determine which hardware and software will be reused which impedes open systems
- Assure that the contract imposes necessary open system interface requirements upon the developer
- Include how an open system environment will be accommodated in support of planning and execution
- Adopt support drivers (product uniqueness, spares, redundancy, graceful degradation, fault detection and isolation, and design stability) influencing the maintenance philosophy and the interdependencies with open system implementation
- Assess the change in maintenance approach via upgrade verses traditional repair and reuse
- Assess the support infrastructure ability to accomplish technology insertion vice traditional repair and reuse[83]

An open systems approach is an integrated engineering and business strategy used to choose commercially supported specifications and standards for selected system logical and physical interfaces, products, practices, and tools designed to overcome ad hoc, redundant and wasteful developmental efforts. MOSA is an enabler that supports program teams in the acquisition community to design for affordable change, employ evolutionary acquisition and spiral development, and develop an integrated roadmap for weapon system design and

[83] Open Systems Joint Task Force. (2004). Program Manager's Guide, *A Modular Open Systems Approach (MOSA) to Acquisition,* (Version 1.2). Washington, D.C. Government Printing Office.

development. Basing design strategies on widely supported open standards increases the chance that future changes will be able to be integrated in a cost effective manner. Designing a system for affordable change requires modularity. An evolutionary acquisition strategy provides a foundation that meets existing needs while providing the capability to meet evolving requirements and threats. An integrated roadmap is a tool for detailing the strategy to deliver a weapon system that is capable, upgradeable, affordable, and supportable throughout its planned life-cycle.

B. AUTHOR'S OBSERVATIONS

There have been many well-intentioned developmental initiatives and funding hurdles that have delayed the 2005 introduction of tomorrow's MCM capabilities. As previously mentioned, changing the culture within the Navy is among the challenges leaders are addressing. Developmental initiatives that have the potential of expanding systems capability also bring to the forefront developmental delays. Developmental initiatives such as Preplanned Product Improvement (P3I) are a deliberate decision delaying incorporation of a system capability but providing growth allocations for system capability. This approach to product improvement has proven to be an instrumental way of aligning technology insertion through science and technology initiatives with those of the acquisition community. Instead of competing against each other, simultaneous efforts within both communities can bring to light a capability to the warfighter in the form of an eighty-percent solution today vice an over reliance on unproven technology tomorrow.

Let's take for example, the AN/ASQ-20 sonar system. This program has been plagued with programmatic starts and stops centered on a lack of developmental and fiscal commitment. In one specific case, the science and technology initiative mandated by Congress to introduce an identification capability added an additional fielding delay to this system. Transitioning this new capability into a developing system came as a programmatic and managerial success story for science and technology, with the introduction of the EOID into the AN/AQS-20 sonar system, but it ultimately added to the delay of a system that has been in the development cycle for over fifteen years. Fielding the AN/AQS-20 in its original form, while simultaneously developing the EOID based on P3I initiatives would have enabled fleet introduction and validation of this new capability earlier than current program restructure plan estimates. This example of technology insertion has been repeated across all of the next generation systems with lasting effects.

The lack of cultural support has echoed across the MIW community for decades, with only the promise of programs that are stove-piped and in direct competition for limited resources. Since the end of the Gulf War, mandates have been delivered from Congressional as well as senior military leaders, but since the end of the Gulf War little new hardware has been fielded. The Office of Naval Research has been in direct competition with the acquisition community. As noted above with the insertion of the EOID the science and technology community has declared victory with the integration of a new technology, while the acquisition community continues to adjust to ever changing requirements. A question routinely asked by fleet operators is "…why not complete a system before attempting to improve that system under development before it's fielded?" It took just over eight years from President Kennedy's Speech to land a man on the moon, but has taken more than ten years to field the first organic MCM system.[84]

C. RECOMMENDATIONS

DoD programs in general are started earlier and allow technological development to continue into product development and even into production, contrary to stable knowledge based ventures by commercial product development. Consequently, the programs proceed with much more unknowns

[84] President Kennedy's Speech to Congress took place May 25, 1961. The Lunar Lander touched down July 20, 1969. Proposed MCM programs were put in motion July 1995. At the time of this thesis, none of the OMCM programs have been fielded.

and thus more risk about required technologies, design capability, and production. Proceeding with lower levels of knowledge available explains much of the turbulence in DoD program outcomes. Metrics, such as those associated with knowledge points, show this to be a predictable consequence. Technology development has the ultimate objective of bringing a technology up to the point that it can be readily integrated into a new product and counted on to meet requirements. As a technology is developed, it moves from a concept to a feasible invention to a component that must fit onto a product and function as expected. Such as tomorrow's next generation MIW system-of-systems. The caveat to tomorrow's organic MIW systems it that each system has been developed as a unique and distinct program, although connected to an overall war fighting objective, these individual programs were developed as separate weapons and sensors designed to meet specific sub-component requirements.

This process of program development places crucial MIW war fighting capabilities in competition against each other in order to succeed and reach production. The problem that has manifested as a result of this approach is an overall reduction in MIW capability in the near-term if at all. Let's take for example the RAMICS system, which was pushed further down the development timeline to make funding available for other systems. As a consequence this delays the only "man out of the mine field" neutralization capability in the near surface and shallow water environment, ultimately placing more risk on Sailors and Marines. This is in stark contrast to the direction mandated by congressional and senior military leaders.

The difficulties identified within this study can be mitigated with the incorporation of an overarching systems architecture as highlighted by the notional MOSA MIW framework. This study illustrated how an overarching plan can serve to improve a system-of-systems development program that can field a more robust MIW capability to meet tomorrow's war fighting vision, specifically the study recommends:

- Developing an overall MIW capabilities architect

- Adherence to systems requirements
- Develop a cultural that supports an MIW architecture
- Provide a culture that enables a stable and committed development environment
- Exercise spiral development concepts to get capability to fleet sooner
- Develop a technology to counter buried mines
- Do not phase out legacy capabilities based on un-proven capabilities
- Validate system development against a traceability matrix
- Provide funding to investigate semi-autonomous/autonomous MCM
- Remedy important equipment shortfalls on current dedicated platforms

Shortfalls such as these must be addressed if the Navy is to meet all of its mining and countermine warfare responsibilities in the face of a shrinking Navy and the growing mine warfare threat. It has been noted there has been a serious imbalance in the allocation of funding and commitment for improvement of MIW programs. If mine warfare is to become a partner comparable in importance with air, surface ship, and submarine warfare in the 21^{st} century there must be far more emphasis placed on execution rather than rhetorical support.

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